

# **PRESENT STATUS OF SOLID WASTE MANAGEMENT AND ITS FUTURE NEED**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**

in

**Mining Engineering**

By

**PIR MOHAN BEHERA**



**Department of Mining Engineering**

**National Institute of Technology**

**Rourkela**

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Under the Guidance of  
Prof. B.K.Pal  
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2007



## **National Institute of Technology Rourkela**

### **CERTIFICATE**

This is to certify that the thesis entitled “**Present Status of Solid Waste Management and its future need**” submitted by **Sri PIR MOHAN BEHERA** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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## **Acknowledgement**

We would like to express our sincere gratitude to the Department of Mining Engineering for us to help us complete our project successfully.

We take great pleasure in presenting this report on our project “**Present status of Solid Waste Management and its future need.**” and in expressing our deep regards towards those who offered invaluable guidance in hours of need.

We take this opportunity to express our heartfelt thanks to our project advisor Prof. B. K. Pal & Mr. Kaushik Dey Without their immense forbearance, constant encouragement and understanding of our project could never have been completed.

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# ABSTRACT

Mining-selected waste (or simply mining waste) can be defined as a part of materials that result from the exploration, mining and concentration of substances governed by legislation on mines and quarries. Identification of the environmental risks associated with such waste requires the characterization and quantification of their different types but also an assessment of the vulnerability of the specific environments contingent upon the geological and hydro geological conditions and peripheral targets.

## 1. - Characterization and quantification of the different types of waste.

This project is based on country-by-country inventory, within the European Union, of sites associated with the management of mining, quarrying and ore-processing waste. It represents the first overview of the current situation in Europe as regards mining waste and presents the current regulatory and management measures specific to each country.

The survey involved two approaches:

- A questionnaire related to the quantities of existing waste, associated with the typology of the mined substance(s), waste deposit(s) and mining systems and ore processing method(s),
- An estimation, on the basis of the different processes employed throughout the production chain in mining operations and their management at each level, of the main types of waste generated over the last five or ten years.

## 2. - Assessment of risks linked to mining waste.

The notion of environmental impact of mining activities is only fully meaningful if it includes a change in the initial environmental parameters, due to such activities. These parameters, which govern the "quality of the environment", may have several components: chemical composition of the waters, soils, etc.; biological diversity; visual aesthetic qualities, etc.

The major risks linked to mining waste for the environment are twofold:

- Risks associated with not only potential pollutant source (*e.g.* acidity and heavy metals in non-ferrous metallic ore) but also the specific environmental context and the presence of targets in the event of liberation. The possible risks from the potential pollutant source (such as acidity and heavy metals) in waste is dependent not only on the mineral characterization of the solid but also on the quality of the potential leachates, the direct environment (soil, groundwater, surface water, air) and the potential targets (human, fauna and flora). The realization of a Geographic Information System (GIS) specific to mining waste quantities and their pollution potential in different environmental contexts would thus constitute a tool in the assessment of risks linked of such materials. At the moment, such systems are used by some regional governments for the information management on land planning. The risk management with a GIS system in mining requires a considerable collection of specific data and additional series of external

analyses. This system should be well defined and studied before to be developed. Then, results can be visualised successfully in the GIS system.

- Risks associated with the stability of the tailings dam, as indicated by the recent spectacular accidents in Spain and Romania. As regards the potential risk from tailings dams, it will be necessary to evaluate on each site the stability of tailings dam. Particular parameters such as exceptional climatological conditions should be carefully taken into consideration during the evaluation. In addition, common minimum safety standards for the design, construction, operation and monitoring should be developed and applied. These minimum safety standards could be built on the know-how of the profession.

### 3. - Improvement of management of waste.

Mines in all European Union countries are governed by a set of laws, generally combined in a Mining Code. The numerous regulatory texts, laws and standards, reveal that mines are a matter of concern to the national administrations. Mining waste are governed by general waste laws and texts. The extent, to which environmental concerns are addressed in these national laws, varies from Member States to Member States.

According to the contract.s tasks, this report refers superficially to some technical processes, the amounts and types of wastes as well as a short description of the national legislation of the various Member States. According to the returned questionnaires, a distinction can be made between the following three types of mine and related generated waste:

- Abandoned/old mines,
- Operating mines based substantially on old operating methods,
- Operating mines based on new design.

For abandoned mines, it is important:

- To undertake site monitoring (including land form(s), geology, soil type(s), hydrogeology, flora and fauna, land use, heritage, overburden and waste characterisation, recycling potential, etc.) to obtain a clear picture of the situation;
- To establish treatment objectives according to required future land use (for example, pollutant level in soil after treatment to be fixed depending on the proposed land use). For operating mines based substantially on old operating methods, it is essential to evaluate the control routine as regards pollution risks and the stability of the tailings dams, and to take all necessary measures to limit risks (for example, installing leachate collection tanks, etc.). Substantial changes in the operation and monitoring phases are likely to be necessary to ensure a sufficient level of environmental protection.



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# Chapter 1

## INTRODUCTION

## **1.1 INTRODUCTION**

Any materials which are thrown away because of no value are called solid waste. Most of the solid waste is disposed in India by land filling and this is most common and important mode of disposal. Solid waste is defined as the material arising from human and animal activities and is being discarded as useless stuff. The processing involves mainly reuse, recycling or disposal.

There are many kinds of solid waste like municipal, industrial, agricultural, industrial hazardous and biochemical waste. The specific challenges for waste management for municipal and industrial wastes are both similar, and yet uniquely different.

Compositions of wastes within each category vary enormously, but as a general rule, industrial waste streams contain a wider variety and more concentrated forms of hazardous minerals and therefore require special technologies and handling procedures.

Disposal and treatment technologies require major long term investments in capital equipment and have ongoing costs. But in addition, the waste and pollution that are treated and disposed off still persist, posing continuous and future threats to the public and environment.

Waste/pollution management strategies based on prevention strive to eradicate both of the above disadvantages because they eliminate the pollution or waste at the source. They tend to be only partially successful in reducing the first disadvantage because in a number of cases, pollution prevention strategies rely on technology investments which have operation, maintenance and costs as well as ongoing costs (e.g. labor, energy). But in general when properly implemented, they are more cost effective than disposal and treatment technologies. Minimization strategies tend to reduce the risks associated with the second disadvantage, but may also offset some of the costs and liabilities noted with the first disadvantage.

When we view the gambit of strategies that are available, a generalized hierarchy based on long term liabilities or risks associated with waste/pollution management and the costs associated with each becomes apparent. The hierarchy is as follows:

### **PREVENTION**

This strategy prevents wastes from ever being formed at the first place.

### **RECYCLING/RESOURCE RECOVERY/ WASTE-TO-ENERGY**

Recycling and reuse of materials, the recovery of certain wastes for reuse (known as resource recovery), and the conservation of certain types of waste into useful energy such as heat, electricity and hot water are strategies which recover the offset costs for overall waste management.

## TREATMENT

When wastes cannot be prevented or minimized through reuse or recycling, then we need to pursue strategies aimed at reducing volumes and/or toxicity. Treatment technologies are processes that focus on stabilization of wastes, reducing toxicity, reducing volume before ultimate disposal, or in some other cases creating limited-use-by-products.

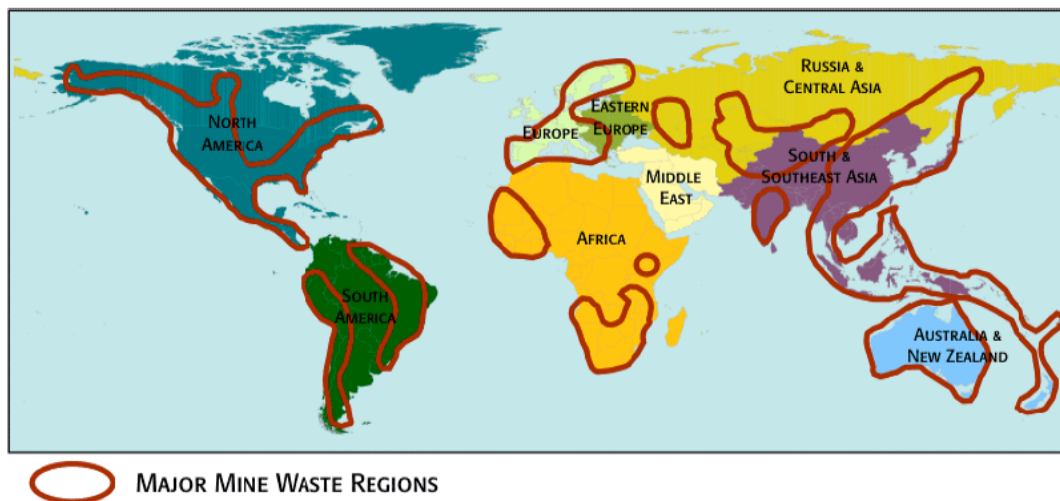
## DISPOSAL

The only other strategy available is disposal. Waste disposal practices are integrated into the environmental management strategies of all municipalities, are integral part of most manufacturing operations, and quite often are amongst the highest direct cost components. From a business standpoint, it is the least desirable strategy and one that can be directly addressed by waste minimization and pollution prevention practices.

## 1.2 SCENARIO OF MINING INDUSTRY

Mining is a major industrial activity that is conducted in locations throughout the world. It involves a full “life cycle” of industrial activities, all conducted in accordance with a range of engineering, legal, regulatory, economic, social, scientific and environmental protocols and practices.

Mining activities date back to 2600 B C with the Egyptian expedition in the Sinai Peninsula. Mining operations occur in every continent except Antarctica. They occur within virtually all of the world’s major biomes, across a broad range of environmental conditions, from the Arctic, to the deserts and rain forests of the tropical belt.



**Figure 1: Major mine waste regions**

Mines are also widely distributed across a wide range of geologic conditions and surface relief. They are often located in mountainous and difficult terrains, where they may be subject to a variety of geologic hazards such as earthquakes, avalanches and landslides. They occur within permafrost areas where frozen ground conditions create particular

difficulties for mining infrastructures. Mining operations are frequently located in very remote areas. Since a mine location is largely constrained by the location of the deposit being mined, there is little flexibility for avoidance of hazards and remoteness, which must be dealt with in the overall design of the mine and its associated structures, including transportation and communications connections.

Figure shows geographic concentrations of major mine waste regions world-wide, based upon those areas where major metal production areas are located world-wide (UNEP, 2003). While the map is a generalized compilation, it demonstrates the globally distributed nature of the mining industry.

Today, the mining industry occupies a unique position in the world and contributes roughly 6% of the world production with value in excess of US \$ 30 trillion.

Worldwide, the mining industry is characterized by enormous diversity. There is, however, a general lack of comprehensive and all-inclusive global inventories associated with the industry. As a result, it is difficult to obtain detailed current data on the levels of production or accumulation of mine waste on an international scale. There are limited statistics on the extent of waste production, and these are reported by mining industry associations or mining industry watchdog groups from different geographic areas of the world. The statistics tend to be collected in different manners and with different levels of rigor or completeness, and so are difficult to properly compare or summarize.

The International Labor Organization (ILO, 2003) estimates about 23 billion tonnes of minerals, including coal, are produced each year. For high value minerals, the quantity of waste produced is many times that of the final product. For example, each ounce of gold is the result of mining and processing about 12 tones of ore; and each tone of copper comes from about 30 tones of ore. Table below provides ILO estimates of the tonnages of a range of different ores mined in 1995 and the percentage of that ore that becomes waste:

**Table 1**  
**Generation of waste from selected metal ore**

<b>METAL</b>	<b>ORE MINED (MILLION TONNES)</b>	<b>SHARE OF ORE THAT BECOMES WASTE, EXCLUDING OB (%)</b>
Iron	25,503	60
Copper	11,026	99
Gold	7,235	99.99
Lead	1,077	97.5
Aluminum	856	70

Source: Gardner and Sampat (2005)

**Table 2**  
**Ore and Waste production for selected metals**

<b>MINING INDUSTRY SEGMENT</b>	<b>TYPICAL PERCENTAGE OF METAL IN ORE</b>
Copper	0.6
Gold	0.0004
Iron	33
Lead	5
Molybdenum	0.2
Silver	0.03
Tungsten	0.5
Zinc	3.7
Uranium	0.3

Source: Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate, Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale, December 2004,

The growth of mineral industry in India has been phenomenal; from just Rs.58 crores value of minerals produced at the time of Independence to a staggering Rs. 55000 crores today. India registers an aggregate production of about 600 million tonnes per annum, through 65 major minerals and 22 minor minerals. It accounts for 11 % of the total industrial production from mining sector which occupies less than 1% of the total land area in the country. With rapid growth of the mining industry in the recent past, and with fast extraction / depletion of the mineral resources, it is natural that land degradation takes place.

Mining is site specific and can only be carried out where the minerals occur. But at the same time, the most important impacts of mining operations, together with beneficiation generating mining Wastes cannot be disregard. The direct on-site effect of the accumulated mining waste is on the area of disposal. In most of the mines in our country, the waste is disposed on the lands. Even if the land is within the mining lease area, the fact remains that it cannot meet other technical or economic requirements.

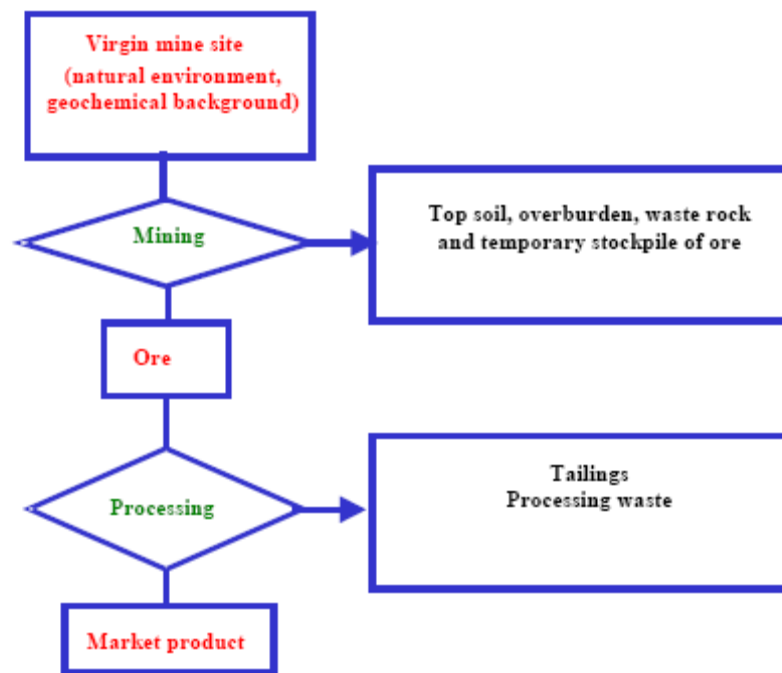
In case of underground mines, the waste disposal problem can be minimized to some extent, by resorting to ‘backfilling’ of mined-out areas by mining waste. The mining waste from the mine is a prime environmental issue which faces significant disposal problems. Therefore, it is necessary, to plan out the disposal of waste in a systematic and scientific manner with due emphasis on environmental protection. Mining typically begins with the exploration for and discovery of minerals, followed by industrial and infrastructure activities that are focused upon the operational extraction and processing of these commodities. Mining also includes those activities that involve the subsequent

decommissioning, closure and long-term remediation of locations where mining has taken place.

### 1.3 WASTES GENERATED DUE TO THE MINING ACTIVITIES

Mining-selected waste (or simply mining waste) can be defined as a part of the materials that result from the exploration, mining and processing of substances governed by legislation on mines and quarries. It may consist of natural materials without any modification other than crushing (ordinary mining waste, unusable mineralized materials or of natural materials, processed to varying degrees during the ore-processing and enrichment phases, and possibly containing chemical, inorganic and organic additives. Overburden and top soil are classified as waste.

The generation of mining waste can be depicted as follows:



**Figure 2: Mining Wastes Types**

### SOLIDWASTE

Solid waste generated in mines is generally the unwanted or discarded solid material. It may include overburden material, low grade ore / rejects, mill tailings, etc which get generated at the mine site in large quantities. Removal of vegetation cover for the purpose of construction, mining or infrastructure development, increases the rate of erosion on the exposed surface and leads to accumulation of sediments with metals at the Site.



## **WASTEROCK**

Waste rock includes the overburden and mine development rock. Industry uses the term “overburden” to refer to the soil and rock that covers an ore body. Similarly, mine development rock refers to material removed from underground mines to access the ore body. These waste rocks are not mineralized, or contain insufficient minerals to process economically. They are typically hauled from the mine site to waste dumps for disposal. In opencast mining, huge quantities of overburden have to be removed in order to win the ore. In underground mining, waste rock is generated at the time of initial development of the mines, e.g. shaft sinking, drifting, etc. Surface top soil is removed first and set aside before commencing the removal of the overburden.

Overburden / waste rock is generally fragmented by drilling and blasting. The top soil may be utilized for re-vegetation / rehabilitation while overburden may be used for backfilling of the mined out areas. A study of geochemical characteristics of overburden may determine the contamination potential of the material and would help in deciding about the future course of action.

## **TAILINGS**

Ore extracted from the mine is beneficiated to separate out the valuable mineral from the gangue by crushing, grinding and concentration. The waste portion of the ore / gangue left out after the recovery of the mineral in slurry form is known as ‘Tailings’. Particle size is an important characteristic of tailings which may differentiate between sand’ and ‘slime’ and has bearing on the method of disposal.

Tailings are the waste products generated during the recovery of the minerals. Typically, the ore is crushed or ground to a particle size of less than 0.1 mm in order to release the valuable constituents. Water and small amounts of chemical reagents are usually added during this process to enhance the separation of the minerals from the ore. (United Nations Environment Programme/International Council on Metals and the Environment, 1998). The tailings are usually dumped into tailings dams or edorable dumps (the latter designed so that the tailings gradually wash into a nearby waterway).

## **SUB-GRADE ORE/REJECTS**

It is the low - grade ore having no economic value or it may be a mix of ore and barren rock. The sub- grade ore is generally of low economic value and is stacked separately at the mine site.

## **LEACHED ORE**

Various processes for extraction of metal from low-grade ores, e.g. heap leaching, pad leaching, etc are being practiced as modern technologies for beneficiation. After leaching/ extraction of metal, the spent ore is either left on the leach pads or removed and dumped elsewhere. For the purpose, highly acidic, corrosive and poisonous materials like sodium cyanide, arsenic, etc are commonly used chemicals. They remain in the residual solution after leaching, and the pulp may contain cyanides and sulphates apart from the spent ore.

## **MINEWATER**

Mine water is the water that collects in both surface and underground mines. It comes from the inflow of rain or surface water and from groundwater seepage. During the active life of the mine, water is pumped out to keep the mine dry and to allow access to the ore body. Pumped water may be used in the extraction process, pumped to tailings impoundments, used for activities like dust control, or discharged as a waste (Environmental Protection Agency). The water can be of the same quality as drinking water, or it can be very acidic and laden with high concentrations of toxic heavy metals.

## **RADIOACTIVIEWASTE**

In general, radioactive waste classes are based on the waste's origin, not on the physical and chemical properties of the waste that could determine its safe management. Other categories of radioactive waste not listed here include mixed waste and NARM wastes (Naturally-Occurring and Accelerator-Produced Radioactive Materials). One common factor for all categories of nuclear waste is the presence of at least some amount of long lived Radio - nuclides.

### **1.3.1 CLASSIFICATION OF MINING WASTES**

Mineral waste can be defined as the 'residues, tailings or other non-valuable material produced after the extraction and processing of material to form mineral products. There is no universally recognized classification of mineral wastes. A classification scheme should take account of the economically important characteristics of the waste, especially its potential end use and the degree of processing needed. A simple scheme proposed by Harrison is shown in Table, with four descriptive categories:

**TYPE 1** waste represents material that could be used with minimal processing, largely as construction material - the classic large volume, low value industrial mineral. The market would be within a short radius of the mine but large amounts of the waste would be removed.

**TYPE 2** wastes would only require a small amount of processing to produce a mineral product, for example removing iron-bearing impurities from a quartz-rich waste to produce silica sand. Large amounts of waste would be removed with a small amount of secondary waste produced. The market would be largely local with the possibility of some national trade.

**TYPE 3** wastes contain small amounts of a valuable mineral that would require a significant level of, potentially complex, processing to recover. The disadvantage to this is that a large volume of the mineral waste would remain and major capital investment would be needed for the processing plant. It is likely that the market for these high-value industrial mineral commodities would be international.

**TYPE 4** mineral wastes contain very small quantities of a highly valuable target mineral (or more likely a metal content) with similar requirements and disadvantages to Type 3.

**Table 3**  
**Classification of minerals wastes**

GROUP	DESCRIPTION	EXAMPLE	POETNTIAL AND USES
Type 1	Unprocessed wastes	quarry scalping, quarry blocks, colliery spoil	fill, low grade road stone, armour stone, brick clay
Type 2	Processed wastes - reclaimed mineral	silica sand wastes, limestone wastes, building stone wastes	silica sand, kaolin, brick clay, mineral filler, aglime aggregate
Type 3	Processed wastes - added-value products	lead/ zinc wastes, pegmatite wastes silica sand wastes	fluorite, barite, feldspar, rare earths, mica, heavy minerals
Type 4	Beneficiated wastes	certain mine wastes	gemstones, high value metals

Research has largely focused on the recovery of the residual metal content of mineral wastes with little effort expended on their value as construction and industrial minerals. If industrial applications could be found for mineral waste it would improve the profitability of quarrying operations and improve the efficiency of resource utilization.

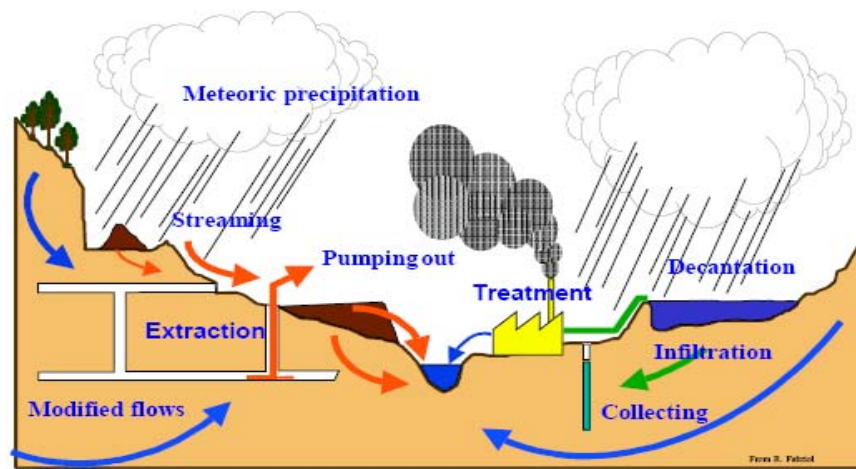
### **1.3.2 ENVIRONMENTAL EFFECTS OF MINING WASTE**

Mining operations, both open-pit and underground, typically produce large volumes of tailings deposits and mine waste piles. One of the most widespread management problems in the mining industry relates to the large volume and/or chemical composition of waste material. Mine tailings and wastes are generally disposed of on land, although limited ocean, lake and river line disposal do occur.

These wastes can affect the environment through the following intrinsic criteria:

- Its Chemical And Mineralogical Composition,
- Its Physical Properties,
- Its Volume And The Surface Occupied,
- The Waste Disposal Method,
- Climatic Conditions Liable To Modify The Disposal Conditions,
- Geographic And Geological Location,
- Existing Targets Liable To Be Affected (Man And His Environment).

Thus, identification of the environmental risks associated with the exploitation of mines and quarries and with ore processing not only requires the characterization and quantification of the different types of waste, as well as a knowledge of the processes used, but also an assessment of the vulnerability of the specific environments contingent upon the geological and hydro geological conditions and peripheral targets. It is important that not all plants or deposits will release any pollutants to begin with meteoric precipitation can transfer pollutant from a tailings dam or a processing plant to the river if the waste management is not efficient. If there is no impermeable layer, below the deposit, the infiltration of meteoric precipitation through deposit can transfer the pollutants to the river *via* groundwater flow.



**Figure 3: Extraction process in mines**

The extraction process can itself modify the water flow and accelerate this transfer. Infiltration can also occur below a decantation basin. All the different risks associated with the waste generated by these activities need to be identified for the management. An example is the failure of mining waste disposal dams, which is potential to damage nearby biotopes and ecosystems. Apart from problems connected with releases into surface and ground waters, we can also add the dispersion of waste fines and heap leaching can also be added.

# **Chapter 2**

## **METHODOLOGY**

## **2.1 METHODOLOGY**

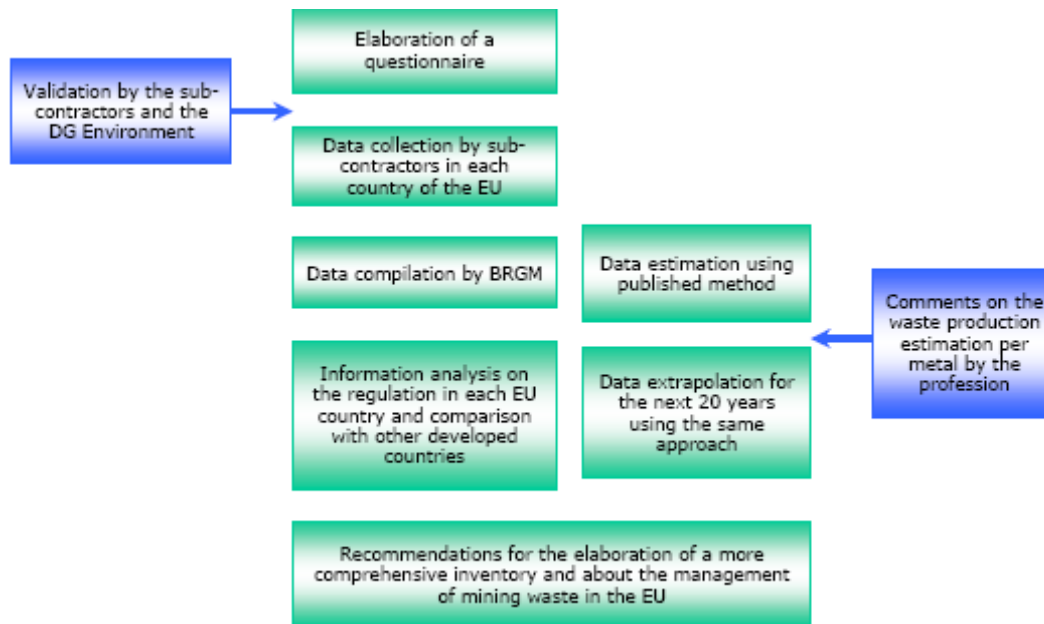
The methodology described here, provides elements leading to the distinction between sites where waste does not present harm to human health or to the environment and sites that may cause substantial and long-lasting harmful effects. The existence of a risk implies the concomitant presence of a hazard source, a mode of transfer and a target (considered as man at this stage of the process), with the four main pollutant transfer vectors being the air, surface water, groundwater and direct contact (soil). If one of the factors does not exist, the risk is not to be considered as such and the assessment of potential risks for the given methodology and usage is no longer applicable.

The following points have to be completed in the frame of this study:

1. Assessment of quantities of mining waste generated,
2. Description of management methods in the different countries ("hazard" point of view) and the type of waste,
3. Identification and analysis of potential environmental impacts associated with waste management.
4. Mining waste management practices and identification of improved actions by the industry,
5. Inventory and analysis of legislation (legislative and standards) in each country. The study of mining waste draws on a vocabulary related to mining as well as to polluted site management.

## **2.2 ASSESSMENT OF QUANTITIES OF MINING WASTE GENERATED**

The basic principle was to identify the waste and define it in qualitative and quantitative terms. An inventory of mining sites per country was essential to assess the quantities of mining waste generated since the start of the mining activities. These inventories supplied information on the substances mined, the typology of the ore deposits, the operating systems and processes. They also included information and data on the quantities of ores extracted and processed, the quantities of marketable products generated, and the quantities of residual waste.



**Figure 4: Project main steps**

### **2.2.1. INVENTORY OF MINING SITES**

The inventory was aimed at identifying for each country:

- Mining sites, whether operational or not, currently being managed,
- Sites for which waste management has been completed.

Whenever possible the information required was both qualitative and quantitative. The data gathered at this stage concerned the identification and location of the sites, the associated mining steps, the operating companies, any known accidents and pollution, any known on-site studies related to overall product and waste management, and a bibliography of the documents consulted.

The work essentially consisted in a documentary research conducted by the subcontractors, supplemented where applicable by direct contact with the administrations and/or mining industry professionals.

Compiling the inventory involved the following main steps:

- Setting a frame and preparing of the inventory forms,
- Search of existing archives (pre-inventory) and files on sites in operation,
- Analysis of the data gathered,
- Location of the sites,
- Validation of the information and possible widening of the search.

### **2.2.2. DESCRIPTION AND ANALYSIS OF MINING SYSTEMS**

The operations performed on a mine site to exploit and utilize an ore deposit can be divided into three main steps:

- Access to the ore deposit (clearance, and galleries producing barren waste)
- In situ ore extraction and selection,
- Ore-processing.

The aim was to identify typical systems accounting for the main techniques of mining and processing mineral substances which are, or were, used in the mining industry, bearing in mind that:

- The topographic, geological and hydro geological situation, as well as the geometry and morphology of the ore deposit, determine the mining method used for its exploitation,
- The chemical composition and mineralogy of the ore deposit determine to a large extent the processing,
- The reserves and economic conditions determine the production rate.

### **2.2.3. TYPOLOGY AND QUANTITIES OF WASTE GENERATED BY THE DIFFERENT MINING STEPS**

Each mining step is liable to generate mining waste, normally with different physical and chemical properties. Their respective volumes, especially for access to the ore deposit, depend on the type of mining method and the type of the raw material. Similarly, their chemical composition depends on the type of ore, its geological envelope and its processing. For example, if two copper ore have respective contents of 7% and 0.7%. For one ton of produced copper, the first one will produce 11.5 tons of waste while the second will produce 164.4 tons of them.

**Two approaches were combined for this assessment:**

- The use of existing data published or supplied by operators or administrations, so as to obtain an approximate assessment of the mining waste flows generated;
- If no data was available, then estimation was made that took into account of the type of deposit, the mining and processing techniques employed and declared commercial production.

The multiplier for coal plays a major role in the magnitude of the global figure of total material extracted. Whilst most overburden removed during opencast operations will be put back, no overburden replacement in this assessment of earth surface change even



though good site restoration programmers can, in time and in certain locations, successfully return the land to up to 80% of original productivity.

The global multipliers and estimates are also a step towards the objective of understanding how the quantities of materials shifted through mining vary in terms of regional climatic and geologic situations, as well as with differing socio-economic conditions. The multipliers can be used with national and local data, but can be checked against the evidence derived from the local case studies. Inevitably, the multipliers will differ greatly from one mine to another and from one means of extraction to another, but by working at global and regional scales as well as through case studies, our aim was to obtain a balanced picture and to be able to make reasonable estimates for those commodities and countries for which there is a lack specific case study information.

## **2.3 DESCRIPTION AND ANALYSIS OF WASTE-MANAGEMENT METHODS**

At each stage of mining operations, management measures are generally taken for the generated waste. These can differ according to the mining operation, and in particular due to the different parameters such as geographic, geological, hydro geological and climatologically disparities. Based on our knowledge of the profession and a bibliographic analysis, we were able to review the main techniques employed.

## **2.4. IDENTIFICATION AND ANALYSIS OF POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH MINING WASTE MANAGEMENT**

At this stage, the objectives were:

- The identification of potential pollution resulting from mining waste and a quick identification of the impact of this type of activity on human health and the environment,
- Compilation of the requested information on specific sites for a simplified assessment of the risks associated with mining waste and environmental repercussions (knowledge of geological and hydro geological aspects, characteristics of the pollution source, etc.)
- Analysis of two recent major accidents (Aznaicòllar in Spain .1998; Baia Mare in Romania - 2000).

### **2.4.1. IDENTIFICATION OF POTENTIAL POLLUTION GENERATED BY MINING WASTE**

Besides the identification of potential pollution sources and their characteristics, our work essentially consisted in:

- Assessing the vulnerability to pollution the sites with active management of the mining waste, and b) their environment; this is done for the different

environments concerned (water, air, soil) and for different possible targets (human, flora and fauna),

- Identifying any transfer forms, as well as the characteristics of the sites containing the mining waste, as well as the physicochemical mechanisms liable to be involved, so as to facilitate, delay or even prevent migration (for example drainage of acid waters,).

#### **2.4.2. NEEDED INFORMATION FOR AN ASSESSMENT OF MINING-RELATED RISKS**

For each main type of mine, try to assess the hazard posed by the waste generated. Estimate an overall assessment by estimating the risk of environmental impact on quantitative and qualitative aspects alike. This estimated risk then indicates the measures to be taken. The simplified assessment, drawing on necessarily simplifying options, helps to differentiate the final waste basically not exhibiting any threat to human health and the environment, from final waste generating significant pollution.

This simplified framework of risk assessment took into account the parameters conditioning the waste-generated pollutant transfer modes (particularly factors slowing down or accelerating migration), and the potential targets liable to be reached, incurring a risk to the environment and to human health.

### **2.5. MINING-WASTE MANAGEMENT PRACTICES AND IDENTIFICATION OF THE NEED OF IMPROVEMENT**

#### **2.5.1. DESIGN OF TAILINGS AND WASTE ROCK FACILITIES**

Examined a number of actual practices in waste management and legislative tracking, as well as voluntary operator/administration agreements.

#### **2.5.2.. EXAMPLES OF ACCIDENTS CONNECTED WITH THE DISPOSAL OF MINING WASTE AND REDEVELOPMENT**

Examine examples of mining-waste disposal-site remediation (yard, heaps or dump).

### **2.6. INVENTORY AND ANALYSIS OF LEGISLATIONS**

Mining activity has subjected it to a body of national legislation known as the Mining Code. Study the state of the play of the different laws in force in the country investigate, as well as foreseeable develop the regulations. Also made an inventory of the different regulations (legislative and legal) of each country, both for general texts and more "thematic" texts covering mining waste.

To address this legal framework, the different partners have questioned the relevant State services concerned with the management of mining waste

# Chapter 3

## ASSESSMENT AND MAIN RESULTS

### **3.1 MAIN RESULTS**

The quantities of the various types of mining waste and their potential polluting capacities are determined by:

- The substance, which may undergo processing (i.e. Its mineralogical context and its association with other elements),
- The characteristics of the layer (depth, nature, size),
- The environment in which the waste is disposed and the regulatory regime in place at the time,
- The time of the mining activity (economic context, treatment used, age of the waste).

### **3.2. ASSESSMENT OF QUANTITIES OF MINING WASTE GENERATED**

#### **3.2.1 INVENTORY OF MINING SITES**

Constructed from the answers received from the sub contractors, Table indicates the number of mining sites (including known abandoned or closed sites) covered by the questionnaire.

Four main categories of ore were considered into which all extracted substances, within the scope of the study, can be placed:

- Ferrous metals,
- Non-ferrous metals,
- Industrial minerals,
- Coal.

The partners adopted different approaches. Some of them made a general study at national level (e.g. Denmark, United Kingdom), while others used an approach of a questionnaire per mining district, or even per mining site. More than half of the mining sites within the European Union are now closed. According to the questionnaires, it appears that whereas almost all metal and coal mining is closed; the majority of industrial-minerals mining is still active. Among the closed sites, some have been rehabilitated or are subject to a rehabilitation project, some are now used as landfill sites for industrial (internal landfill) or domestic waste, whereas others are abandoned.

**Table 4**  
**Number of Mining sites (including known abandoned or closed mines)**

Country	Ferrous metals		Non ferrous metals		Industrial minerals		Coal	
	total sites	closed sites	total sites	closed sites	Total sites	closed sites	total sites	closed sites
Austria	2		1		>500 *		2	
Belgium	>500	all	>300	all	>4700	>4500	>4000	all
Denmark	local	closed	a few		Opencast pits		lignite	Closed
Finland	5	5	38	26	12	7		
France	17	17	160	158	119	77	81	77
Germany	3	1	3	3	105	1	44	2
Greece	3		6	1	15	1		
Ireland			21	17	6	4	4	4
Portugal	8	7	9	9			1	1
Spain	20	18	58	45	47	20	73	25
Sweden	3		20	14				
United Kingdom	35	35	31	29	22	?	23	?

In the north of European Union, the number of rehabilitated sites appears to be higher than in south of European Union. The acid mining drainage is less important for the old mining sites. The metals contained in waste can be finding in small quantity. The potential risk is low. It should also be noted that the number of sites quoted in the following table cover only the sites mentioned in the questionnaires by the subcontractors. This table should not be interpreted as presenting all sites in the European Union. The methodology used in the questionnaires was a first attempt to carry out an inventory at the European level. The difficulties faced during this exercise should serve as lessons for future work at Community level.

### **3.2.2. DESCRIPTION AND ANALYSIS OF MINING SYSTEMS**

The ore consists of minerals, each containing a combination of chemical elements, whose common forms are oxides and sulphides. In addition to coal, there are two main types of mineral raw material:

- Industrial minerals, usable as such after concentration and purification (kaolin, potash, talc),
- Concentrates resulting from the extraction of an element present within a mineral, and demanding further processing steps after separation of the mineral from its gangue.

For metals, the process culminating in the industrial product generally involves three steps:

- Ore or mineral processing (enrichment of the ore by separating the mineral from the gangue),
- Extractive metallurgy ( pyrometallurgy, electrometallurgy, hydro - metallurgy), which culminates in a material having a certain degree of purity,
- Refining. A technical (hence universal) definition of a mine includes all developments, structures and ore-extraction and-processing equipment, as well as all temporary and permanent storage dumps for materials and/or waste resulting from the exploitation and upgrading of a mineral resources.

A mine is a raw-material production site that comprises the phases of ore extraction from the deposit to the concentration of the useful mineral. It is organized around large civil engineering, equipment and consumables infrastructures. It manages all the inputs and outputs attached to it, whether liquid (wastewater, effluents), solid (fines, dump stocks, plant releases, semi-finished and finished products, chemical reagents) or gaseous (pyrometallurgy).

However, it is also necessary to add an administrative definition that can substantially modify this technical view with the local regulatory framework. As a rule, the substances are usually classed in two categories, those governed by the regime of mines and those, which depend on the regime of quarries. The origin of this distinction can be found in the rarity of the substances in the mines, a rarity that has historically incited the States to arrogate ownership.

Substances coming under quarry regulations belong to the owners of the land, who can either exploit them themselves, or entrust the exploitation to third parties in exchange for payment. Although exploitation in this case is governed by common law, the same Administration can supervise the operations. The most common rule is to define the list of concessible substances in a law, all the others pertaining to the regulations on quarries. However, a number of mining codes in the world set the list of substances belonging to the regime of quarries, with all the others belonging to the regime of mines.

This difference in classification of mineral resources is an important factor that ultimately affects the management of products and waste and the overall qualification as an extractive industry or the more specific qualification as a mining industry, whereas the extraction methods and problems associated with waste management commonly display many common features. Given the variety of morphologies of natural deposits and the large variety of useful mineral substances, numerous mining techniques have been developed to address the problem of extracting ores and materials. Technological evolution has consistently improved these different techniques, which generally culminate in different types of waste and thus waste-management methods.

**a) Three criteria are conventionally recognized to define the limits of a deposit:**

- Geological limits of the mineralization, which correspond to the distribution zone of known mineral resources. These limits are liable to change in time due to possible progress in the general degree of knowledge of the actual mineral accumulation and its geological environment. Exploration engineers and technicians (geologists, geophysicists, geochemists, etc.) are generally involved in the process of delimiting the ore. However, this cannot be stated since the information technology and databases have considerably improved and can be simulated successfully with 3D computer models.
- The economic limits, which differentiate the mineral accumulation or mineralization of ore or material. Thus economic concepts are used to define zones of rich ore(s) and zones of lean ore(s) within a deposit from the contents of cuts, which are calculated according to a number of criteria, based on a balance between general production costs and net income, including a profit margin. Market fluctuations could lead to the consideration in turns of one part or another of the mineralization as a rich ore, or as a lean ore, or as mining waste. Economic engineers are involved in determining the feasibility of mining an ore or a material.
- The technological limits associated with the optimal conditions for mining the ore. Depending on a number of morphological criteria associated with the ore (depth, dissemination, or segregation in a formation or datum level, dip, type of substance), a mining method designed for optimal recovery in terms of quality and cost will be set into action among the many mining methods available for surface or underground workings. For the miner, only the part of the ore accessible by the mining techniques actually implemented defines the deposit.

It can also be mentioned:

- The limit grade: this is the content of an elementary mining block (bucket or shovel in quarry, blasting of a working front) such that the concentrate produced from this block, paid for with the metal prices of the time, pays all the costs of extraction, transport and processing of this block, to the exclusion of financing costs and depreciation,
- The cut-off grade is the bottom content selected by the operator, below which no block will be mined. It is easy to demonstrate that the optimization of a mining operation is successfully achieved when the cut-off content is equal to the limit content.
- Those in which the passage from the ore to the waste is settled and where it is not possible to make a sorting or selection within the deposit. The geo statisticians refer to this as "all or nothing".

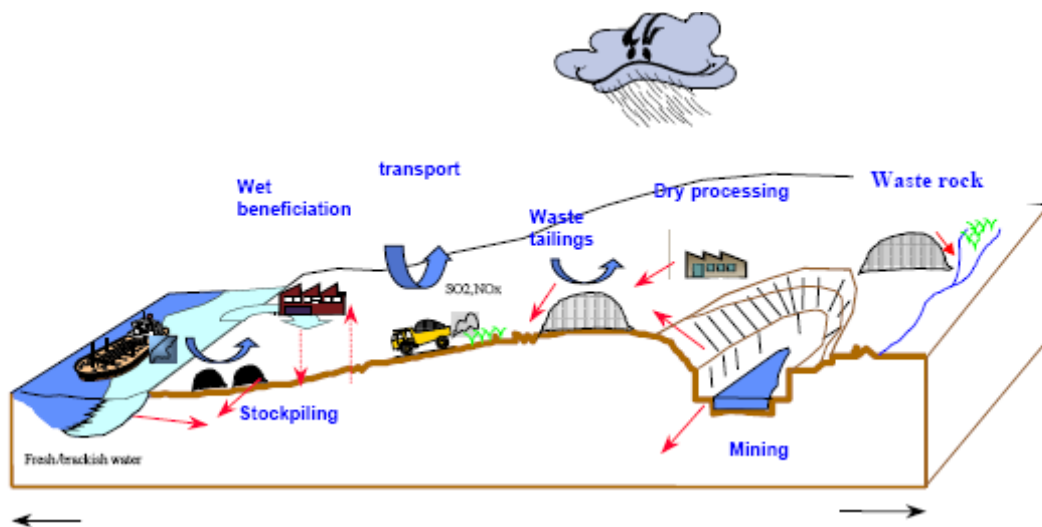
- Those within which a selection can be made according to the different cut-off contents. These deposits display a variable tonnage depending on the cut-off content.

## b) Types of mining operation

Several factors (location, geometry, morphology, depth, economics, environment, and even mining tradition) underlie the choice of method(s) for mining a specific ore deposit. Depending on this method, and on the size of the mine site, the projects display different ore-extraction capacities, and consequently larger or smaller quantities of mining waste. A major difference from the environmental standpoint can also be demonstrated in the composition of the waste associated with the mining method employed.

### Open pits and quarries

There are many alternatives within open pits and quarries but the great principles are identical. Most industrial materials and shallow metallic deposits (< 300 m) are mined by this method, which is the cheapest in practice. The scale of the projects, and particularly their depth, is conditioned by an economic threshold above which it is better to continue mining through underground workings. As a rule, after the stripping operations (removal of the soil and superficial horizons), actual mining is carried out in successive steps, imparting a roughly conical shape to the mine.



**Figure 5: Different steps of a mining activity**

The mining of each step or bench produces a tonnage of extracted material corresponding to the overburden surrounding the deposit, which is sent directly to the waste dump, and a tonnage corresponding to the ore that is selectively routed either for storage or directly to



the processing plant. The variation in the ratio between the tonnage of waste to be extracted and the quantity of ore recoverable (also called stripping ratio) strongly conditions the economic viability of the mine. If this ratio becomes too high, especially when the quarry is deepened, it is no longer economically profitable to continue strip mining.

### **Underground mines**

When deposits are difficult to reach from the surface (depth, cliffs permitting side access), the only alternative is underground workings. A broad range of methods are available (chamber and pillar, long-wall, under-level caving, under-level stopping and filling, shrinkage) all of which are roughly adapted to the characteristics of the ore or the geometry of the deposit: dip of the layers or veins, thickness, continuity of the mineralization, grade of ore (disseminated or massive). The workings are generally opened by levels with a 60 m vertical spacing and then sublevels at 15 m intervals. Two criteria are vital for all these workings: selectivity of the ore and its percentage recovery. All the operations conducted in the ore are connected to one another and to the surface by a series of passages, all opened in the overburden surrounding the deposit: shafts, inclines, drifts, chutes, cross-cuts for personnel and machine access, for removal of ore and drainage water, as well as for ventilation.

This organization of the operations has the following consequences:

1. The ore extraction capacities are generally much lower than for surface quarries;
2. The quantity of waste produced per unit of ore mined is much lower than for surface quarries;
3. The ground area of this type of underground mine is considerably smaller than for surface quarrying, except for sub horizontal layers;
4. The mechanical risks are different (subsurface collapse, structural weakness around shafts and other inclines).

### **c) Mining phases and operations**

The operations carried out on a mine site to exploit and upgrade a deposit can be divided into three (or sometimes four) main steps:

1. Preparatory or development operations providing access to the deposit: the scale of these clearance (or stripping) operations in the case of an open-pit mine and for drilling drifts, shafts or inclines for an underground mine, vary considerably according to the characteristics of the deposit. Opencast pits generally produce about ten times more waste on average than underground mines, which are more selective.
2. Ore extraction operations (or workings), and crushing or preliminary sorting operations to optimize the transport and grade of crude ore. Before its transfer to the processing unit.

3. Ore processing (in many cases for metallic mines), set of operations corresponding to generally grouped in a specialized unit (called concentrator) used to separate the mineral phases containing the useful substances from the waste gangue; the product of the plant, enriched with useful materials, is called the "concentrate". In most cases, the concentrate is the marketable product. Note however that mines of so-called high assay substances (iron, manganese, bauxite) are often simplified installations only rarely containing ore processing units on site; as a rule, in these cases, the ore is exported without processing to distant sites where its metallurgical conversion is more advantageous, particularly in terms of energy also used in mine sites, in addition to physical and physicochemical methods (gravity separation and flotation). This applies in particular to gold ones (cyaniding) more recently to copper and nickel oxide ores (heat leaching or autoclave), and even more recently, to copper and cobalt sulphide ores (bio-leaching). In some exceptional cases, no physical or chemical process is applicable. A smelter must accordingly be installed nearby and, in these conditions, forms part of the mine (nickel saprolite).

### **3.2.3 Typology of waste generated by the different mining steps**

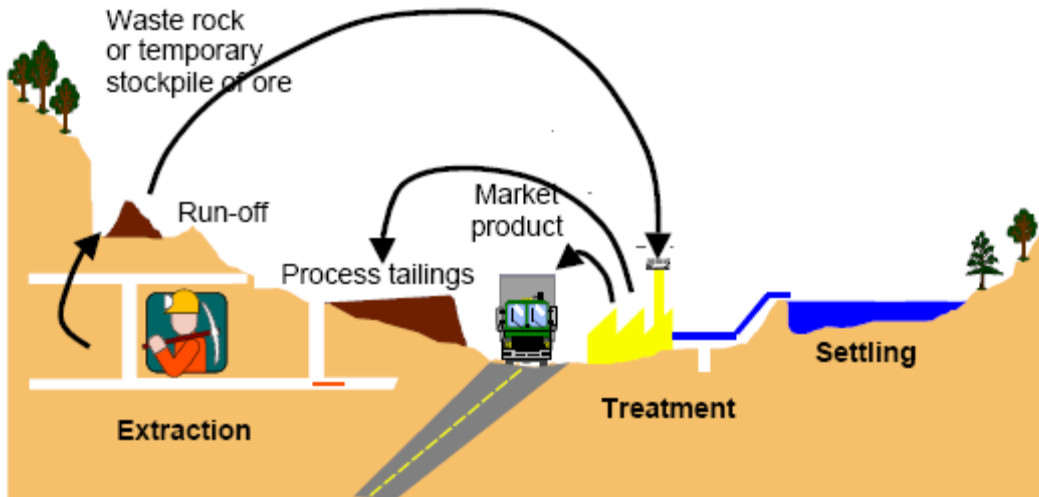
Each of the ore-mining and-processing steps can generate mining waste. This waste generally has different physical and chemical properties, resulting in different potential environmental impacts. The respective volumes of waste produced essentially depend on the type of deposit and the technological alternatives used for mining and for ore processing; stripping of the deposits in strip-mined quarries is often one of the steps producing the most waste during ore extraction operations. The chemical composition of the waste varies considerably according to the substance mined and the nature of the geological formation containing the deposit.

The main types of mining waste in addition to topsoil and overburden can be classed into two categories:

- Waste rock (mine rock piles);
- Tailings (processing waste);

We can mention two further types of "waste" because of the need of their environmental management:

- Temporary Stockpiles of ore;
- Slags (Out of the Scope of the Present Study, Because Slag Derives From A Later Stage of Metal Utilisation)



**Figure 6: Different types of mining activity waste**

It is interesting to note that for some Member States, the term .waste. is not applied to residues (coarse or fine) resulting from the quarrying and processing of crushed-rock aggregates. In the most part, these are saleable products, which will be sold if local market conditions are favorable. In addition, both coarse and fine residues are routinely required for site restoration and landscaping.

#### **a. Waste Rock**

Waste rock is hence durably unused extraction products that are generally stored indefinitely in a landfill site which, for economic reasons associated with transport costs, is located in the immediate vicinity of the main mining centre. The quantity of mining waste that can be stored at a mining centre varies considerably and mainly depends on the selectivity of the mining method. As a rule, opencast pits and quarries generate much more mining waste than an underground mine.

The main type of waste rock is generated by surface (or barren rock) stripping to expose the shallow ore. This is rock that is weathered to varying degrees, although increasingly fresh with depth and showing the geological characteristics of the local surrounding material. Its composition is similar to the rocks of the sector. The largest (in tonnage) quantity of barren rock comes from stripping for opencast mines. In underground mines, these barren rocks are generated by the passages (shafts, crosscuts).

#### **b. Tailings (processing waste)**

At a mine, an ore mill normally abuts on the extraction centre to produce the first marketable products (metallic concentrates, sorted ore, and ingots). The Technological processes are very different according to the type of substance mined, and the modernity

of the technologies employed (flotation, leaching, and biotechnology). These units produce various types of waste, which can include:

- Aqueous solutions from cyaniding,
- Slurries of finely ground particles that have undergone one or more types of physical or chemical treatment, and which frequently contain one or more industrial additives that have participated in the conversion process (xanthates, miscellaneous salts, starch, etc.). These tailings are normally dumped in a sort of lagoon or settling basin within an embankment at the exit of the mill ;
- In some case, atmospheric releases from sulphide roasting. Emissions to air would come under the heading of environmental impact.

Mill waste is generally referred to as tailings, or releases or effluents. It is generated by the various mineral-upgrading processes employed to meet demand. For a given mineral, it will have different physicochemical properties according to the conditions in which it has been generated. Its volume and variety has increased to match raw material demand, combined with the proliferation of upgrading methods and their degrees of sophistication. It is found in solid, liquid and gaseous form. Waste is generated at all levels of the recovery process to upgrade the minerals, within the same process chain, and is considered as ultimate or stripped of useful elements. Its content depends on the time that it was generated.

Through the years, solid waste has evolved in line with technological progress, from multi-centimeter grain size with a still high content of the desired element (i.e. low tonnage and hence low exchange surface areas culling or manual sorting waste) to micron grain size with very low chemical contents (i.e. high tonnage implying commensurate exchange surface areas flotation waste, colloids, fines). The release mesh varies from one ore deposit to another, depending not only on the level of technology but also on the geological and mineralogical characteristics.

### **c. Ore stockpiles**

Intermediate storage of products, ore stockpiles are not waste and are normally temporary dumps of lean ore at the mine site, depending on the cut-off content, which may vary with time. This type of mine project management is included in the overall mining plan. This management requires maintenance on the mine site for a period sometimes longer than a decade. Selectivity materials correspond to ores of lower grade than the limit assay. These ores have a content which, while lower than the limit content when stored, can be handled later without loss in the processing plant when it is not be saturated, in which case it is treated as lean ore.

#### **d. Slags**

Slag does not fall under the scope of the study. In many old mines (Fe, Cu, Sn), the ore or concentrate was also burned or smelted nearby to remove certain components (e.g. sulphides) in order to produce a purer marketable product. In this case, slag heaps can be found on these old sites, forming a specific type of waste. Ash produced by cleaning furnaces or smoke stacks is frequently associated with them. These oxidized products are found either accumulated near the mine, if smelting was conducted nearby, or often stacked in heaps near the smelter. This study does not carry on slags.

### **3.2.4. QUANTITIES OF WASTE GENERATED BY THE DIFFERENT MINING STEPS**

Two approaches have been combined to estimate the quantities of waste generated:

- The study of the data provided in the inventory of mining waste carried out by the subcontractors in the questionnaires. This investigation made it possible to obtain a realistic estimation,
- Estimation based on the quantities of ore produced by mine sites in the various countries. Using ore grade and the relationship between the run-of mine ore and the commercial concentrate, it is possible to estimate a weight or volume of the waste generated during the lifecycle of the exploitation.

#### **a. Approach by the questionnaires:**

We defined two main categories of waste according to the relevant step of the exploitation: waste rock and tailings (process waste). For each type, we defined the quantity of waste stored on site and the quantity of total produced waste. The difference is the quantity of reused (recycled for example) waste stored waste is all material, which has not been reused, poured back into or used to refill mining shafts. The quantity of stored waste should be less than the quantity of total waste, but this was not always the case due to certain inconsistencies found in the returned questionnaires. Some sites did not give any statistics on total mining waste or total tailings, and others only provided the quantities of stored waste. It appears that the stored mining waste or stored tailings are the most reliable data generated by this approach.

#### **b. Approach through an estimation based on production:**

This estimation was established starting from the known data concerning the production of metal ores and industrial minerals within the European Union between 1986 and 1995. The poly-metallic deposits (such as Zn-Pb-Cu or Cu-pyrite) were classified according to their dominant production. It was not possible, within the framework of this study, to distinguish the various types of deposits according to their morphology, their mineralogy, etc., parameters that are potentially important with regard to the quantities and nature of the produced waste. The lowest size limits represent an artificial cut-off, often defined by

the contained metal and which takes into account only the significant mines, albeit giving a good general idea of the mining activity. The upper limit gives a good approximation of the largest known deposits. Such a calculation gives a very rough total cumulated volume of the waste produced by mining and of the non-economic mineralization rejected with the dumps or stored for a possible later valorization. We are conscious that the ratio between production and ore can vary by a factor 10 or more, within EU. There is a significant difference between opencast and underground mines (less waste in the underground). Underground mines in general have significantly higher ore grade. Taking copper as one example, ore grades in European mines vary from 0.4 to 5%. An other example is the amount of residues generated from crushed-rock aggregate operations which vary according to rock type quarried, as well as being dependent on the type and degree of quarry processing. Certain sandstone quarried for high PSV road stone may generate up to 40 % fine-grained residues, whereas limestone quarries are more likely to generate around 10-15 % residues. However, most of this will be utilized over time.

### **c. Comments**

All estimations need to be validated within each country. For example, an assessment of the estimations for Sweden show those corrections must be made on ratios proposed by Ian Douglas and Nigel Lawson:

- Global waste for ferrous metal should be 108 Mt,
- Global waste for non ferrous metal should be 327 Mt,
- Waste from crushed rock aggregates should be close to 0 as the quarries are stored in good rock and there is nothing that cannot be used,
- Waste from sand gravel should be close to 0 as in that country, the deposits are glacial sands and gravels where everything can be used,
- For refractory materials, the quartzite is mined in open-pits with selective methods and hardly any waste is created. The estimation of waste should be 6 Mt;
- Coal has just been exploited as by-product from clay pit.

The estimated quantity of waste should be then close to 0. Then, carrying out a precise estimation of the volume of mining waste in EU would be possible but would require a complete site-by-site inventory, which could be inspired by the inventory questionnaire presented here. The results should be controlled by the different actors in the mining field of each country. A classification of the ore by types could reduce work. A precise determination the volume of mining waste would also require consultation of mine registers (when they still exist), evaluation of productions and processing to measure the real quantities of waste still on the sites by knowledge of amount of potentially reusable material (low-grade ore for later processing, waste for road aggregates or backfill material). Often, natural erosion has moved part of the waste, especially when the waste is stored at the river's edge (a frequent in areas of broken relief).

The data on mining waste quantities, collected *via* the questionnaire, has been expressed in tonnes, cubic meters or tonnage per year, depending on the usage in each country. Several estimations and approximations were thus needed.

A certain number of sites were not mentioned in the questionnaires, particularly in Spain and in East Germany. For example, the mining of the cupriferous schists in the area of Mansfield, Germany ended in 1990<sup>89</sup>. Total production of the site was 2.6 Mt of copper and 14200 t of silver. All the neighborhood mediums (air, water, and soil) are polluted, mainly because of the degradation of metallurgical fall-out dust. Currently, only measurements of the setting safety of the metallurgical sites are undertaken. The data relating to this site need to be added to the provided data.

#### **d. Evaluation of future quantities of demobilized materials from mining activities**

In the future, on the base of the EU currently exploitable ore reserves, in terms of the current economic context and current production rate. The results are not based on the current ratio of production. According to the questionnaires, the closures of most mining sites in the European Union, are planned relatively early (a lot of them before 2010), but new mines will open. The quantities of waste would be certainly less than those presented here, as is confirmed by some production rates given by the subcontractors.

### **3.3. DESCRIPTION OF MINING-WASTE MANAGEMENT METHODS**

#### **3.3.1. DISPOSAL OF MINING WASTE AND TAILINGS**

Disposal of coarse mining waste consists in conversing large areas with dumps or in filling abandoned open-pits

By order of importance, the disposal of tailings is generally by:

- Terrestrial impoundment (tailings ponds),
- Underground backfilling,
- Deep water disposal (lakes and sea),
- Recycling.

##### **a. Terrestrial impoundment**

Terrestrial deposition is the predominant method for tailings disposal. It concerns fine waste and slurries such as mill tailings. The principle of tailings dams (or ponds) is to dispose of the tailings in an accessible condition that provides for their future reprocessing (once improved technology or a significant increase price makes it profitable). Actually, the vast majority of tailings facilities are design as permanent disposal facilities. Tailings are often transported to the impoundment *via* pipelines.

##### **b. Underground backfilling**

This method is possible only for ore deposit without communication with an aquifer. Such an operation is usually costly and will be carried out for stability and safety reasons.

### **c. Deep water disposal**

The disposal of tailings and solid waste directly into bodies of water although sometimes used in past operations, is rapidly becoming non-authorised as a standard practice due to the significant pollution effects it can have on the receiving waters and the possible subsequent impacts on the livelihoods of the local communities. This method requires specific conditions. and specific impact assessments. There seems to be a consensus among scientists that an appropriately designed underwater disposal of sulphidic tailings is the ideal solution from an environmental point of view in the short term with control of the level of water.

### **d. Recycling**

Coarse mining waste and especially barren rock is sometimes considered as materials for roads, building foundations or cement factories, depending on its geotechnical and geochemical characteristics. Recycling is not classified as disposal. In the German Potash Industry, the solid waste is 22% recycled, 58% dumped and 7% backfilled; the liquid waste is 8% deep well disposal and 5% discharged into rivers (Kali und Salz GmbH). Waste rock may have no market at the moment occurs. If a market will emerge later, the rock stored temporarily can be sold as aggregate when environmental specifications are met. With new techniques, the tailings can be reprocessed.

## **3.3.2. ENVIRONMENTAL ISSUES**

Some waste generated by mining operations, due to the mass it represents or to its chemical (or physical) nature, can pollute the environment, in particular media as water, soil, vegetation, and targets like the fauna and human.

Among the environmental problems, associated with tailings deposition, the principal ones are:

1. . Safety and stability of dams,
2. . Water pollution,

### **a. Safety and stability of dams**

Tailings dams need to designed for the mine life and shaped at the initial stage. This reduces the need for reshaping dams at a later stage and so avoids costly earthworks and .double handling.. We are conscious that in practice, the building of tailings dam at the initial stage of a mines life is difficult, due to the fact that in most cases the ore reserve, the mine life and hence the total amount of tailings will increase over time. This is due to a continuous development of mining and processing methods and to the fact that the knowledge on the ore body will increase with time. The placement of waste on steep slopes is to be avoided when possible so as to reduce the risk of land slip and dam failure,



particularly in areas of high rainfall and areas prone to landslides, earthquakes and tremors.

Embankment of dam is shaped during the building stage so that slopes are gentle enough (15 to 20 degrees, or 27% to 36%) to reduce erosion and to allow vegetation to become established and so reduce the negative visual impact of unsightly waste rock.

A major factor in the design of tailings embankments is stability, from a geotechnical point of view. Factors influencing this geotechnical stability include:

- Embankment height,
- Embankment slopes,
- Strength of the embankment and degree of compaction,
- Permeability of the embankment and groundwater position in relation to it,
- Strength and compressibility of the embankment foundations.

Guidelines are available that define certain good geotechnical characteristics of embankments (UNEP (199 6) Guide to Tailings Dams and Impoundment. Bulletin 106).

The type of dam embankment to some extent dictates the system of tailings discharge to be adopted. For example, embankments that are designed as water retention structures are made of low-permeability materials and tailings are discharged well upstream of the embankment.

## **b. Water pollution**

Acid rock drainage can be a significant concern in the management of waste rock but is not in the scope of that study. Water pollution may appear at different stages in the management of tailings. For example, failure of the discharge may cause spills and damage the surrounding environment. Alternatively, rain and process water may create leachates when passing seeping through tailings (essentially in respect of tailings from ferrous and non ferrous ores), giving rise to:

- Sulphide oxidation and potential acid generation,
- Sulphide oxidation and production of soluble salts,
- Metal leaching and migration to the surrounding environment,
- Leaching of residual process chemicals in the tailings, e.g. Cyanide, acids, alkalis,
- Geochemistry and toxicity of the waste materials impacting on humans, vegetation and fauna.
- These can also result from:
- Seepage through and below impoundment walls,
- Percolation to the subsoil and groundwater,
- Overflow of the dam walls or spillways.

### **3.4. IDENTIFICATION AND ANALYSIS OF POTENTIAL ENVIRONMENTAL IMPACTS OF MINING WASTE**

The environmental issues mentioned above refer explicitly or implicitly to the risks, related to the hazards and the potential environmental impacts. There is a need to recall the main types of impact generated by mining waste, beginning with a comment on the "relative" notion of environmental impact before looking at the source of potential pollution, the transfer pathways and the targets. These are three aspects needed for a simplified risk assessment. The behaviour of the waste is dependent on the waste management procedures put in place.

#### **3.4.1 IDENTIFICATION OF POTENTIAL POLLUTION GENERATED BY MINING WASTE**

It is important to attribute a ranking to the different environmental impacts from mining waste, representative of their real importance. Starting with point zero, the duration of these impacts and their evolution with time, and their treatment, must be examined in light of the different phases of operations, and treated by preventive, curative or specific confinement measures.

It is hence important to distinguish between harmless impact, or harmful chemical impact or pollution, and harmful physical impact or detriment. The notion of environmental impact is here only fully meaningful if it includes a change in the initial environmental parameters due to mining activity.

The environmental impact must be assessed against the environmental quality targets for the affected zone, not against the initial environmental aspects. The parameters, which govern the "quality of the environment", may involve several components: chemical composition of the waters, soils, the biological diversity; and aesthetic qualities, etc. To be able to judge the degree of impact, it is therefore necessary for:

- Each component to be expressed in terms of a quantifiable parameter (pH, concentration of a metallic element, quantity of matter in suspension, measurement of biological diversity, speciation of species conditioning their mobility),
- The measured value of each component to be compared with the range of its natural background values for the environment of the mine site, i.e. those that existed before the mining operations, and which are often unknown. This point is important since ore deposits are usually indicated at the surface by strong natural geochemical anomalies that are often used by the prospector to discover the deposit. Any survey aimed at determining the impact of a mining operation (anthropic pollution) thus requires the most accurate possible knowledge of the natural environment of the site before operations.

From the geological aspect, and given the diversity of geological contexts, the geochemical background. can vary considerably in the different countries of the

European Union. From the hydro geological aspect, various parameters must be taken into account to define the hydro geological settings, such as the lithologies of the geological formations (particularly as regards presence or absence of a clay layer, the type of porosity and permeability, the topography of the investigated site, the typology of pollution sources).

### **3.4.2 ASSESSMENT OF MINING RELATED RISK: POTENTIAL SOURCES OF POLLUTION**

Every ore, whether metallic or non-metallic, is rarely mono-mineralic, but composed of a complex mineral paragenesis liable to contain a large number of potential pollutants, in addition to the material to be upgraded. Moreover, industrial processing methods use chemical components, which may also create pollution. These components are present in small quantities and are often organic, dissociating fairly rapidly in other molecules.

Consequently, analysis of the pollutant potential of the extraction and physical preparation of an ore, whatever its type, must take into account the pollutant potential of each mineral species, including those resulting from the in situ weathering of the primary minerals making up this ore and its surroundings.

This study must naturally consider both the major and trace elements present in the concerned ores. Since excavation and reworking gives rise to different physicochemical conditions from those prevailing in the deposit in place, the chemistry of the elements concerned must also be considered. Some mineral species are believed to be stable in the natural environment and harmless to man and the environment, apart from possible detriment attributable to the fines fraction. The pollutant potential of this type of ore has to be analyzed individually in accordance with the processes employed for their conversion and for their adaptation to their intended use. Ores that fall into this category include aluminium (bauxite), tin (cassiterite), iron, manganese, talc, titanium (rutile or ilmenite), and zirconium. Analysis of the pollutant potential associated with ore processing has to take into account the industrial methods used to process the concerned ore in order to extract the useful components (e.g. flotation, cyaniding, and amalgamation).

#### **a. Non-metallic minerals and materials**

Some rocks mined in quarries or mines may contain sulphides that convert to sulphates during mining and are soluble in contact with water. Such acid drainage waters can cause the release of heavy metals. Some non-metallic materials mined for anthropic uses nonetheless have a pollutant potential (see Table 11 and Annex n°5) when associated with certain minerals, especially those containing metalloids. Primes among those are:

- Arsenic Minerals,
- Barium (Barite) Minerals, Combined With Lead and Zinc,

- Fluorine Minerals (Fluorite, Cryolite),
- Sulphuric Minerals,
- Fossil Materials Such As Coal And Graphite Containing Carbonaceous Matter,
- Evaporitic Materials (Rock Salt, Potash, Gypsum, Nitrates, Borate),
- Zeolites, Which Are Basically .No-Pollutants., But Have The ability To Substitute The Water Present in Their Crystal Lattices with a Variety of Substances (Nh3, Hg, Cl), that Makes them .Potentially Pollutant materials.

#### **b. Metallic minerals and materials**

Some metallic elements are considered stable in the natural environment such as iron, magnesium and manganese. Most metallic ores exhibit hazardous components

### **3.4.3 ASSESSMENT OF MINING RELATED RISKS; TRANSFER PATHWAYS**

Many parameters have to be considered in characterizing the geological and hydro geological aspects related to the transfer of pollutants. Given the complexity of the subsoil in the European Union, the chosen characterization criteria should be as simple as possible and are normally given binary treatment in order to facilitate the identification of the setting which the analyzed site is located.

The selected criteria, which should be defined during the prior investigation campaigns (soil survey, in-depth diagnosis), characterize either the geological formations immediately below the site, or the specific conditions of the site. The following section describes 16 geological and hydro geological contexts where generic waste management measures have to be taken. A number of elements have to be considered in the determination of these geological and hydro geological contexts.

#### **- Formations comprising the site substrate:**

A geologic substrate is described with several terms (see table 12) whose definition is given below:

- Type of the waste deposit
- Formation type on which the waste is dumped: it may be impermeable (consisting of low permeability materials, like clay) or auriferous; in most of the cases analyzed, it concerns formations either capping an aquifer, or the unsaturated zone of the aquifer,
- Formation of the thickness, particularly for a clay cap rock protecting a Groundwater reservoir: thin (for settings where the pollution from waste crosses the impermeable

horizon) to thick (for cases in which the cap rock still exists and Accordingly will delay pollution transfer),

- The structure of the litho logical formations making up the aquifer: unconsolidated or compact formations

- The type of aquifer porosity: porous, fractured or karstic - the type of aquifer: unconfined or confined.

- Specific conditions of the site:

- The topography of the geographic sector in which the site is located: e.g. in a Valley or on a slope,

- Rainfall,

- Groundwater flow direction and speed,

- Presence of groundwater catches works, locally altering the flows,

- Seasonal fluctuations in aquifer water.

Other specificity connected with the geographic location may also complicate the local systems considered above, namely, the superimposition of several aquifer types, the natural heterogeneity of the subsurface formations, their chemical properties (in terms of exchange capacity, sorption), the existence of resurgence zones, etc. The different cases developed here intentionally present relatively simple situations.

It is clear that the realities in the field will inevitably confront the investigator with more complex cases, likely to result from the combination of several simple situations. Table 12 serves as an entry key for different "subsoil" scenarios. It refers to the numbered data sheets presenting a typical system and a brief explanation of the case concerned.

### **3.5. IDENTIFICATION OF IMPROVED MINING WASTE MANAGEMENT BY THE INDUSTRY**

#### **3.5.1. DESIGN OF TAILINGS AND WASTE-ROCK FACILITIES**

The location of a new mine is the key issue, and a considerable amount of information of the immediate environment is required in order to make the .best choice. in terms of tailings and waste-rock facilities. The choice also concerns minimization of mining waste (backfilling, selective waste handling of various types of wastes). Many factors must be considered when selecting sites for the surface disposal of mining waste. Planning during the preliminary design stage of any mine development generally considers the following environmental issues:

- Existing land use,
- Where to site dumps in relation to topography, drainage systems, water bodies and residential areas, so as to minimize dump instability, water pollution (surface and underground), dust problems and adverse visual impacts,

- Location and direction of the groundwater flow, which can influence the migration of any contaminants reaching the groundwater,
- Allowing sufficient area around dumps for bunds or trenches to collect acid water runoff or for the placement of dams to collect seepage (leachate), runoff and sediments,
- Prevailing wind direction and strength, as waste dump materials may cause dust and noise problems downwind,
- Distance of disposal sites from the mining area or processing facilities,
- The sitting of sub-economic grade material for possible future reprocessing when either technology or commodity prices permit,
- Avoiding the sitting of tailings deposits (which can fluidize) above existing or proposed underground workings.
- Minimizing transport-energy costs from the processing plant through using gravity transport when possible.
- If a waste deposit can be located as close as possible to both plant and mine, this reduces the amount of land required to be disturbed and significantly reduces transport related operating costs, particularly if any of the material is likely to be reclaimed for further processing. However, the selection of the location of waste facilities should take into consideration the environmental consequences of such decisions.

### **3.5.2. TAILINGS DAM STABILITY**

Terrestrial embankments (dams) in areas subject to earthquakes or landslides are particularly vulnerable. Foundation conditions (rock or sediment type, compaction rate, etc) are important in terms of safety, environmental protection, reducing risks of seepage and groundwater pollution. It is important that impoundment is designed with future closure in mind, so that it will remain stable, secure and virtually pollution free, with little maintenance required. Standards should be laid down to ensure the safe management of tailing dams. They do not prevent the realization of a specific study.

### **3.5.3. WASTE CHARACTERIZATION**

The waste characterization is crucial to ensure a proper waste management and should systematically take into account all the following parameters:

- The different mineral species (speciation) present in the primary ore, including weathering minerals,
- The non-upgraded elements present, even in very low concentrations, can cause significant pollution if the tonnage handled is large,
- The industrial processes employed to treat this ore, as well as their yield and efficiency in terms of the recovery of the elements present in the various raw materials used,
- The material balance of the materials employed and those generated in the processes applied,

The state of the potential source is related to its behavior into liberation of pollutants. A liquid source could be more transportable than a solid one.

The two phases of the potential pollution source are:

- **Solid phase:** grain size distribution of materials, uniformity and isotropy of the soil, density, water content, permeability, pH, redox conditions, organic carbon and clay contents,

- **Liquid phase:** pH, redox conditions, total and dissolved carbon contents, content of suspended matter (particularly for surface waters and effluents), major physicochemical composition (sulphate, chloride, phosphate, nitrate concentrations, as well as iron and manganese), aquifer lithology, hydraulic gradient, effective porosity.

Other parameters which are considered:

- **Type of source:** dump/waste deposit or polluted soil, the latter possibly including waste or backfill spread on the surface,

- **Type of waste deposit/dump:** aboveground or buried.

#### 3.5.4. WATER MANAGEMENT

Different steps have to be checked:

- Avoid pollution of groundwater and surface water,
- Collect and treat the polluted water and leachates,
- Minimize the water volume that require treatment,
- Manage the dust.

Measures used to control seepage from tailings dams include:

1. Controlled placement of tailings,
2. Foundation grouting,
3. Foundation cut-offs,
4. Clay liners,
5. Under drains and toe drains,
6. Artificial liners.

1. Controlled placement of tailings is the most cost-effective method of controlling seepage. Provided that the tailings are of low permeability they will form a cohesive system.

2. Foundation grouting involves the injection of fluidized material and could not be effective unless there is high permeability rock beneath the impoundment or where there are high permeability zones in the rock.

3. Foundation cut-offs are necessary when soil foundations are sand or sand and gravel. A significant reduction in seepage may be achieved by construction of an earth fill cut-off or a slurry trench cut-off wall. They may be applied to extremely weathered rock such as laterised, highly permeable rock.

4. Clay liners can be effective in areas where the storage is located in an area of high permeability. They are susceptible to cracking on exposure to the heat (by sun), which can increase permeability.

5. Under drains below the tailings should be constructed. The drains act to attract the seepage water and discharge it to a collector system, ideally for recycling to the process plant.

Some methods of collecting and treating this seepage are required, such as:

- Toe drains,
- Pump wells,
- Seepage collection,
- Artificial wetlands.

6. Artificial liners are used to line waste disposal facilities, often with provision for drainage layers beneath the membranes to collect any leach ate, which leaks past the first. However, these liners do not seem to be always appropriate for all tailings disposal situations (such as in case the underground water is confined and spouting out).

The control of the water balance in the system should include process water, tailings water, storm water runoff, precipitation, seepage from impoundment and into the ground, and evaporation

Measures to minimize acid drainage and pollution from water containing dissolved metals, salts and process chemicals.

- Minimize percolation to subsoil and groundwater, by low permeability of the substrate and low permeable cover,
- Minimize seepage through the impoundment wall,
- Collect seepage by a collection and treatment system,
- Minimize influx of surface runoff by trenching and by-passing the tailings
- depository,
- Maximize circulation of process water,
- Minimize infiltration of water into the tailings dam.



We can mention one of the most efficient ways to minimize the oxidation of sulphides and subsequent production of acid drainage, namely water covers (or water saturation).

A number of parameter has to be considered in selecting the solution to treat the different media affected, in relation with the investigated site. A partial list of factors necessary for this pre-selection of treatment techniques likely to be applied to the three media (air, soil, and water) is presented below. Others are specific to the pollutants to be treated. For each of the geological and hydro geological contexts, a panel of actions is presented, aimed to limit or treat a potential pollution. These actions should be applied to reduce the effects if pollution of mining waste is shown. They are related to the different aspects (design, waste characterization, dam stability, water management).

The recommended actions concern low permeability of the layer and the embankments, water and leachates treatments, aftercare actions and some extreme cases. The presented actions are just generic measures requiring detailed programmes for the implementation on site.

# **Chapter 4**

## **INVENTORY AND ANALYSIS OF LEGISLATIONS**

## **4.1. INVENTORY AND ANALYSIS OF LEGISLATIONS**

Mining today, like other industrial activities, is subject to environment protection laws, regulation and standards. Mining operation and environment protection requirements are most commonly implemented through a variety of different legal tools, such as:

- Mining legislation,
- Environmental planning and assessment legislation,
- Environment protection legislation,
- Other legislation and standards, including occupational health and safety.

Government roles in environment protection are gradually evolving in response to changing perceptions in mining operations. Developments in the ownership and control of mines and metal production facilities have greatly influenced both the locations of mining and investment in new mines in Europe and around the world.

### **4.1.1 Canada**

More specifically, in Canada, laws have been enacted both for the Provinces and at federal level. Apart from radionuclides, which come under the Atomic Energy Control Bureau, the Canadian Federal Ministry of the Environment has stiffened the legislation on effluents generated by mining waste. The main points that emerge are:

- Prohibition to dump certain substances,
- Establishment of limit values on quality of the effluents,
- Determination of limit contents authorised in terms of chemical compounds present in the materials stored.

This regulation applies to:

- Geotechnical stability of disposal sites,
- Pollution control in the different environments,
- Environmental impact of disposal, management, remediation and redevelopment operations.

The standards drafted at the federal level in Canada represent maximum basic values and the local environmental agencies must define the specific values for the sites concerned, values, which may be lower than the nation wide values. The regulations on water management are based on controlling releases and in this sense, reinforce the responsibility of the mine operators in the management and treatment of the waste within the geographic limits of the mine, using the best technique at the optimal economic level.

The guide values applied at the periphery of the mines are determined according to each type of operation, based on the hydro geological, physical, chemical and biological properties of the waters receiving the effluents.

#### **4.1.2 Australia**

In Australia with a large mining industry, the mining industry is governed by the Australian Mineral Industry Code for Environmental Management, published in 1996. This Code requires the companies to publish a public report each year on the environment (Public Environment Report). The terms of this report must normally at least contain information on the following subjects:

- Position of the company with respect to environmental permits,
- Position of the company with respect to environmental laws,
- Any prosecution or conviction,
- Regulations or orders relative to the environmental legislation specific to the industry and the site,
- Major incidents,
- Facts or circumstances which may have an effect on the environmental aspects and which have had an impact on the performance of the company.

#### **4.1.3 Malaysia**

Malasia's current mining legislation is limited in scope because it deals almost exclusively with the small-scale alluvial tin mines that have dominated the country's mineral sector. In order to attract foreign investment, Malaysia has proposed new legislation for large-scale hard rock mining. The proposed legislation includes specific requirements for tailings management such as:

- A detailed plan,
- A design that complies with good engineering practice,
- Construction under the supervision of a professional engineer,
- Stability against any static and dynamic loading,
- Free board not less than one metre.

#### **4.1.4 Mexico**

The Mexican official standard, approved in 1997, stipulates the compulsory requirements for site selection, construction, operation and monitoring of tailings dams.

These requirements include:

- An environmental impact study,
- Compliance with laws governing the preservation of historical or cultural heritage,
- Assurance that there will be no percolation of toxic leachates to the nearest aquifer or surface water body during the next 300 years,
- Approved plans for surface and groundwater monitoring,

- Detailed characterization of the underlying geological structure and the mechanical properties of rock formations and soil deposits,
- Land surveys of the site to delineate elevations and features such as roadways and pipelines,
- Compliance with civil works design standards for dams of the Federal Electricity Commission,
- Monitoring instruments for dams over 50m in height.

#### **4.1.5 European Union**

At the European Union scale, no specific legislation exists today on waste from mining operations, neither the extraction of industrial materials, the processing of ores or industrial materials. Each of the member States has its own mining and environmental legislation which more or less completely and sometimes separately covers the different branches of activity mentioned above.

European legislation distinguishes between horizontal legislation relative to environmental management and legislation by specific sectors, products or types of emission (Air, water, and waste.). The horizontal legislation concerns the environment management: the collection and assessment of the information on the environment and on the impact of a large number of human activities. The vertical legislation concerns the specific sectors.

Mining waste stands for .waste resulting from prospecting and extraction treatment, and storage of mineral resources.. The definition of waste is laid down in Directive 75/44/EEC on waste as amended by Directive 91/156/EEC. Mining waste therefore covers all material which .the holder discards or intends or is required to discard.

Mining waste would cover in particular topsoil, overburden, waste rock and tailings, which are discarded. The environmental aspects are playing a growing role in the mining of ore. The extraction of mineral substances can no longer be considered without reference to an environmental legislative framework. Among the Directives listed in the following paragraph § 2.6.2., we can mention the European Directive of March 3, 1997 (97/11/CEE) (J.O. L73 of the 14/03/97) modifying the Directive n° 85/337/CEE related to the assessment of the effects on the environment of some projects (private or public). It specifies in its appendices the types of projects, which must be subject to an evaluation of the environmental impact. Among these human activities, we can quote the quarries and the open pit exploitations whose surface exceeds 25 ha and the plants producing non-ferrous metals from ores, concentrates or secondary matter. The quarries or the smaller open pits and the underground mines are prone to evaluation according to criteria determined by the Member States (Appendix n°II of the Directive).

## **4.2 FRAMEWORK OF EUROPEAN LEGISLATION ON INDUSTRIES, WASTE AND WATER**

A specific legislation on mines and mining activities does not exist in the European Union. Mining operations are covered indirectly by more general legislation than that of the IPPC. In fact, in certain Directives, the mine is excluded if specific legislation exists. There is a need to train the decision-makers and for stiffer legislation in connection with the enlargement of the European Union. Legislation could be one of the tools to prevent accidents as the two mentioned earlier (Spain and Romania).

On the 23rd of October 2000, the European commission published a communication on safe operation of mining activities [COM(2000) 664 final] presenting existing Community environmental legislation related to mining activities. The Communication sets out three priority actions envisaged to improve the safety of mines, relating to industrial risk management, management of mining waste and integrated pollution prevention and control:

- an amendment of the Seveso II Directive to include mineral processing of ores and, in particular, tailings ponds or dams used in connection with such mineral processing of ores<sup>1</sup>;
- An initiative on the management of mining waste covering the environmental issues of the management of mining waste as well as the best practices, which could prevent environmental damage during the waste management phase<sup>2</sup>;
- A Best Available Techniques reference document (BREF) describing the Best Available Techniques of waste management to reduce everyday pollution and to prevent or mitigate accidents in the mining sector<sup>3</sup>.

The European legislation relating to industries and waste must be regarded as a framework in which the Member States and the Union, in close collaboration, must develop the basis of a durable protection and a management of underground water.<sup>23</sup>

## **4.3 LEGISLATION ON WASTE**

The definition of responsibilities at national level in the area of waste is governed by Article No. 5 of the Council Directive 75/442/EEC of 15 July 1975, which states that “the Member States shall establish or designate the responsible competent authorities, in a given region, for the planning, organization, authorizations and control of operations pertaining to waste dumps”.

**The European Directive concerning landfill of waste:** Directive 1999/31/EC of the Council, dated 26 April 1999. Directive 1999/31/EEC on landfill of waste entered into force on 16 July 1999 and will be effective 16 July 2001. This Directive lays down a number of provisions related to safe disposal of waste. According to the scope of this

Directive (Article 3.2), the deposit of non-hazardous inert waste resulting from prospecting and extraction, treatment, and storage of mineral resources as well as from the operation of quarries is excluded from the Directive. In addition, according to Article 3.3, Member States may, under certain circumstances, exempt from certain technical provisions of Annex I of the Landfill Directive the following waste: non hazardous, non-inert waste resulting from prospecting and extraction, treatment, and storage of mineral resources. In this Directive, the surveillance programme for water, leachates and gases was set up. The results of this monitoring must be sent to the competent Authorities. In Article No. 12, the Directive specifies the inspection and monitoring procedures to be set up. Hazardous and non hazardous (not inert) wastes from mining activities are covered by this landfill Directive.

It should be noted that the Landfill Directive was adopted primarily to regulate the disposal of waste into normal landfill sites. All the issues related to tailing ponds management have not been specifically considered in this Directive. However, there are a number of provisions of the Landfill Directive, which are relevant to mining waste management. This provision of Directive 1999/31/EC should apply to this waste and should be laid down in the mining waste initiative.

Article 4 requires that different types of waste should not be mixed (some specific examples can be in contradiction, these can be considered excluded from the scope of the Landfill Directive, because considered as treatment operations). Article 7 includes essential provisions for the management of mining waste. such as the requirement for a plan for closure and after-care procedures. Specific issues are added such as the expected long-term behaviour of mining waste, the question of dam stability and the requirement that a waste management plan be drawn up and accepted by the competent authorities. Article 14 specifies that deadlines of existing landfill sites should be further elaborated.

The definition of treatment in the Landfill Directive does not specify in technical details the treatment to be applied to each type of waste. This could include various techniques, which are applied for the disposal of mining waste.. Processes generating waste should be designed in such a way as to reach the objectives of waste prevention as well as to facilitate the handling and recovery of mining waste.. The treatment requirement should apply to some type of waste and not to certain exemptions as certain waste from potash or coal mines.

The article 11 mentions that the composition, leachability, long-term behavior and general properties of mining waste. to be landfilled should be known as precisely as possibly. One of the main characteristics to be tested is the potential for the production of acid leachate. There is a need for a rapid test (the current one may take several weeks). The other tests standardized in CEN/TC 292 could be applied when the material is not sensitive to oxidizing conditions. In conclusion, mine waste management, as an integrated part of the mining process cannot be compared directly to the landfill concept. This issue actually presents opportunities and set limits:

- Process design will have an impact on the waste and the properties of the waste can be influenced through changes in the process, - the waste management practices put in place will influence the characteristics of the waste,
- The tailings pond is often used as a passive water treatment facility and can be used to increase water recycling,
- Backfilling of tailings underground means certain requirements on infrastructure and mine planning.

**The European Waste Catalogue and the list of hazardous waste** have been revised (Decision 2001/118/EC) are currently being revised. Certain mining waste is now covered in the list of hazardous waste.

**Council Directive 92/104/EEC 3 December .92** refers to tailings dams as well as other EU environmental legislation which is applicable to the sector. The increase in the technical definition criteria for sites able to receive disposal facilities and operating criteria inevitably means a decrease in the capacities of the sites and higher costs. This consequence encourages the companies to minimize the production of waste and to identify new recycling opportunities.

#### **4.4 LEGISLATION ON INDUSTRIES**

**The European Directive on pollution prevention 96/61/EC of 24th September 1996 (IPPC:** "Integrated Pollution Prevention and Control (IPPC)" is the title of a framework Directive adopted in September 1996 presenting the measures and procedures necessary for an approach to protect human health and the environment, by preventing or minimizing emissions from industrial installations. This regulation stipulates inter alia that the operating permits must be based on environmental quality standards (air, water, soils and waste), considering the requirements of the best available techniques (BAT). This document on the best available techniques takes into account each metal and presents the processes and techniques applied the consumption and metal emission levels. 24 Installations producing "chemical concentration of metals produced from ores" are included in Annex No. 1 of the Directive on classified installations. The activities concerned must use secure techniques derived from the Best Available Techniques, monitor and prevent any accidental pollution. It is the duty of the local authorities to specify the notifications and financial aspects in case of environmental impact. This Directive has been applicable since 1999 to new activities, and will be mandatory from 2007 for existing operations.

The IPPC Directive may not cover all sites in the European Union where tailings dams are used. They could not be production sites, not be producing crude metals, or not be regarded as landfills falling under category 5.4 of Annex 1 of the Directive.

**The Council Directive 85/337/EEC** relative to the assessment of environmental impact. This Directive, related to the assessment of the effects of certain public or private projects on the environment, has been amended by Directive 97/11/EEC and Directive



92/104/EEC relative to the safety and health of the workers in surface and underground mining industries. It is an integral part of the laws on mining operations in most of the Union countries. It clarifies the 1985 Directive on certain points:

- It broadens the field of application to new projects,
- It specifically requires an examination procedure through which the member States will determine the projects requiring an environmental impact assessment,
- It reinforces the requirements pertaining to projects with inter-border effects,
- The Member States had to transpose the Directive on the Environmental Impact Assessments before 14 March 1999. The Commission set regulatory measures against a number of States which had not done so (Austria, France, Luxembourg, Germany, Greece, Spain and the United Kingdom) by this date.

**The Directive related to Strategic Environmental Evaluation:** Political agreement was reached on the future Directive on the strategic environmental assessment. The aim of this future Directive is to ensure that the environmental impacts of certain plans or programmes are identified and evaluated during their preparation and before adoption.

**The Environmental Management System (EMS) and the Audit and Eco-Management Scheme (EMAS):** The concept of Environmental Management System was set up on 29 June 1993 (1836/93) and amended in Regulation (EC) N°761/2001. It allows the voluntary participation of the companies in the mining sector in an audit and eco-management scheme. This structure addresses sites, which have established an environmental management system and produced a public statement on the environmental management of the site. This system applies to industrial sites and waste disposal sites, recycling sites, mining operations and electric power plants demonstrating their systematic and approved approach to any potential impacts.

#### **Council Directive 76/464/EEC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community**

For relevant pollutants, which have to be identified out of a wide range of other substances including cyanides and heavy metals, the Member States must establish national emission reduction programmes. In relation to mining activities, there is pollution potential from certain dangerous substances, which may cause a deleterious effect on the aquatic environment. The identification of such pollution leads to a requirement of authorisation of discharges containing the relevant pollutants. Hence, an effective pollution control of point sources from mining would be possible under the Directive.<sup>25</sup>

## **4.5 SPECIFIC LEGISLATION ON WATER**

At European level, the management of water is based on an integrated management. This management depends on quality standards of the environment, limiting values of

emission and other legislation related to the habitat, the clarification sludge, SEVESO or the impact studies.

Directive 2000/60/EC adopted on 22 December 2000 is the operational tool for the implementation at national level of the European Water Policy.

The additional legal texts are mainly the following:

- **Directive 75/440/CEE** on potentially drinkable water, which introduces the notion of protection of raw water resources and defines target values.
- **Directive 76/464/CEE** on hazardous substances (two lists: the most hazardous substances which need authorization and an inventory and the other substances which only need authorization and a reduction programme,
- **Directive 80/68/CEE** on underground water (substances from list I do not be rejected, substances from list II have to be studied and need an authorization before any reject). This Directive mentions the precautions to manage the pollution by monitoring, asks for information when underground water is under two countries and asks for information to the Commission,
- Some other Directives such **82/176/CEE** or **84/156/CEE** on mercury, **85/513/CEE** on cadmium,

#### **4.6 REGULATION ON THE CLOSED MINING SITES**

No European regulation exists today that applies specifically to close mines and closure procedures. However, since the mine sites can be identified under cover of the Landfill Directive, Articles No.12 and 13 of this Directive (1999/31/EEC) specifies the closure conditions of this type of site. Existing operations, as far as they are covered by the Landfill Directive, have to comply with the Landfill Directive after the closure of the mine. Proper closure and remediation procedures should be applied for mining waste disposal sites.

Old mining sites can be taken into account within the framework defined by the work groups CARACAS (concerted action on risk assessment on contaminated sites) or CLARINET (Contaminated lands and risk assessment network on European technologies).

#### **4.7 COMPARISON OF LEGISLATION RELATED TO MINING WASTE IN THE MEMBER COUNTRIES OF THE EUROPEAN UNION**

We gathered the great principles of each national legislation within the European union as regards waste and more specifically of mining waste. In a general way, the overall scope of the raw materials acts is to ensure that exploitation of raw material deposits

takes place as an element of sustainable development and is balanced against other planning needs and also takes into consideration various environmental and socio-economic aspects. The raw materials planning are incorporated into the overall land-use planning.

The study of the answers given by the questionnaires shows that the previous European legal framework is integrated in the national legal framework of the different countries of the European Union.

The mechanisms for controlling mineral extraction in part reflect the historical evolution of the ownership of mineral rights. A number of Member States have a strong tradition of centralized control over mining and quarrying through a mining authority, which is usually part of the department of trade, industry or economic affairs. Although the same countries generally have a land use planning system also complements the mining legislation; the principal means of control usually still resides with a mining authority. In England, the control of mineral extraction is exercised through the Town and Country Planning Acts administered by the Department of the Environment, but implemented principally by local planning authorities.

Environmental assessment seems to be harmonized in the extractive industry. Coordination of procedures has been achieved. Nevertheless, some significant variations between countries do exist in term of permitting procedures and level of environmental requirements.

Restoration of worked out mineral workings is considered as a high priority in most Member States, and restoration conditions or their equivalent are in use in certain countries. Aftercare conditions are less common, although the principle of long term management of restored land is broadly accepted.

# Chapter 5

## CASE STUDIES

## **5.1 CASE STUDIES OF IMPACT ASSESSMENT IN GOA AND SUKINDA INDIA**

### **5.1.1 ENVIRONMENTAL ASPECTS OF MINING AND WASTE RECOVERIES:**

Environmental protection and management is the primary responsibility of the mineral industries and the same lies with the mine planners, operators, Research and development organizations. Government also plays a major role for setting environmental standards and implementation of the same through individuals and mining organizations. Increasingly the government, mining industries and local community are working in tandem to protect the environment towards sustainable development. In this context, several regulations were enacted by the Government from time to time for mitigation of the problems faced by the mining industries with appropriate abatement measures. To address the problems of the mining and sustainable development, both on regional and local scale two sites were selected for this purpose. One site comprises the pale-Pissurlem group of mines covering 11 iron ore mines in north Goa district and the other site comprises 11 chromites mines in Sukinda valley of Jajpur district in Orissa. The objective of these studies was to assess the regional environmental management plans so as to enable different executors and regulatory authorities to frame necessary guidelines. The results of these studies can be used as a model for taking up similar studies in other areas having cluster of mines.

The major mining sites namely Sukinda valley chromite belt in Orissa covering 11 chromite mines and iron ore mining belt in north Goa covering 11 mines, were taken up for the assessment of the environmental impact. This was necessitated due to large scale mining operations in clusters and to suggest abatement/ remedial measures. The project addresses the problems of different types of environmental indicators, in the form of EIA, EMP studies of specific mines based on the integration of REA studies. The outcome of three years of effort of investigations involved generation of base line data on regional scale, followed by development of EIA and EMP at the mine level.

The data acquisition for conducting the investigations includes generation of the data on air, water, noise, soil, climatic conditions, ground vibrations and socio – economic parameters. The risk analysis performed has brought out clearly the emitters, pathways and receptors for evolving remedial measures to be incorporated in EMP document for these mines and on the region as a whole. It will help mining entrepreneurs to contribute towards sustainable development in Indian mining sector.

### **5.1.2 METHODOLOGY AND APPROACH**

Necessary environmental assessment and management tools developed towards the analysis of environmental indicators for the risk assessment followed by the preparation of detailed EMP, administration document and subsequent auditing strategies are summarized in table.

In the study areas, as per the details summarized in table 1, data generation, analysis and corresponding EMP, EIS document preparation, environmental auditing methodology for the overall environmental assessment and management tools have been given in the case study.

### **5.1.3 CASE STUDY 1: SUKINDA VALLEY CHROMITE BELT**

Sukinda valley chromite deposits are located in the state of Orissa. About 90 % of the chromite production of the country is obtained from this area. The chromite deposits are of disseminated type occurring in the form of bands, extending over a considerable strike length. Mining operations are by mechanized / semi – mechanized method followed by the beneficiation for up gradation of the ore. The study area covers 11 numbers of chromite mines. The REA and mine wise EMP of these 11 mines is based on the data generated from monitoring stations judiciously selected for analysis of water, air, noise, dust and other vital parameters. Monitoring has been carried out as per the norms laid down by Indian bureau of Mines and MOEF. The location of the monitoring stations both in core zone and buffer zone. The study has helped to evolve potential emitters, pathways and receptors. The areas and factors requiring attention are listed below.

Surface water quality exceeds the standard for drinking, aquatic life, and fish for Cr in most of the Damsal nala valley downstream Gurujangpal village. Surface water is suitable for irrigation only in the upper part of the valley.

Paddy sediment quality exceeds the Cr standard for agricultural soil in most of the fields and Ni in few places investigated.

Ground water quality exceeds the standards for drinking water in most of the wells that were investigated.

The exposure assessment of the population and ecosystem to key substances are risky in character and has allowed the identification of five major issues by EMP Water treatment

General pit slopes for their stability and reduction in waste generation. Disposal of waste and tailings and their rehabilitation. Development of green belts and monitoring network.

Chromite contamination is observed in the entire zone of influence of mining activity. Traces of mercury higher than drinking water standard from sources, which could not be identified, have also been noticed in some areas. It has conclusively brought to the fore that ultimately the main risk in the chromite belt is associated with the drinking water contamination with hexavalent chromium and transfer of these pollutants throughout the food chain to include paddy field, fruits and vegetables and aquatic flora and fauna.

**Table 5**  
**Main results of the REA monitoring: Sukinda**

TOPIC	MAIN FEATURES
Waste and ore	Ore : Cr = 48 % Tailing : Cr = 25 % Dump : Cr = 7 % Ni up to 6 %
Leaching tests	Leachate of the Nala sediment: Cr total = CrVI 2-12 mg/l Leachate of the paddy sediment : Cr total = Cr VI = 0.7 mg/l
Surface water	23 out of the 31 monitoring stations exhibit Cr VI above drinking water standards (up to 3.4 mg/l)
Ground water	32 out of the 33 monitoring wells exhibit at least one Cr VI above the drinking water standard ( up to 0.6 mg/l) 6 wells exhibit Hg above drinking water standards ( up to 0.01 mg/l)

The impact have affected the whole valley and in the framework of the EMPs, solutions must not only be sought at their sources, i.e. at individual mining lease scale (exploration, waste management and effluents treatment), but also regionally; i.e. at valley scale transport, land use, water resource management). This will need involvement of mine managements, inhabitants in and around mining belt, state and central government administrative agencies to effectively ensure sustainable development of this very important chromite bearing belt in India.

#### **5.1.4 CASE STUDY NO. 2: NORTH GOA IRON ORE MINES**

The study area includes north Goa iron ore mines having priorities related to environmental issues. The study included 11 numbers of important mechanized opencast mines, which are privately owned. Most of the iron ore produced from these mines is being exported. The iron ore is soft and in nature and contains around 60 % Fe.

The REA and mine wise EMP of these mines is based on the results of the monitoring carried out on parameters such as air, water, noise and ground vibration etc. over four seasons period in the study area.

**Table 6**  
**Main results of the REA monitoring (Goa)**

TOPIC	MAIN FEATURES
Waste and ore	Ore : Fe > 57 % Dumps : Fe - 40 to 50 % Tailings : Fe – 30 to 50 %
Surface water	3 stations are influenced by sea water 7 stations exhibit Fe concentrations above drinking water standards during the dry season
Ground water	Ground water analyses show that base metal contents are below drinking water standards. 6i stations exhibit Mn concentration above srinking water standards during the dry season. Mn background is high even far of the pits and other mining activities.
Pit water	Chemical characteristics are generally similar to those of ground water except higher content for Fe and Mn.
Tailing waters	Salinity occurs in the beneficiation plant near the Mandovi River.

The associated risk with each media investigated were included because they are of direct concern to local population and the mine workers and also because they can assist decision makers in the choice and implementation of remedial measures.

The negative impacts associated with mining activity in the study area are as under:

Surface run offs from exposed mine surface (benches), waste rock dumps and pit dewatering pose significant problems during the rainy seasons through erosion and carry over fines and suspend matter in nearby agricultural fields. They cause water courses silting and render paddy fields barren contributing with the waste rock dumping, resulting in progressive destruction of farmlands.

The volume of solids waste generated in one of the main concerns besides removal of overburden to win the ore (OB to ore ratio being > 2.5:1) pose major problems in storage and reclamation.



Air quality in the mining sites has been degraded due to mining activities in the form of high levels of SPM and RPM in the dust. The dust is being generated during extraction, transportation, dry beneficiation etc.

Thus the important issues related to EMP to be tackled are:

- Disposal of waste and tailings and their rehabilitation
- General pit slopes for their stability and reduction in waste generation
- Improvement of infrastructure facilities – transportation, roads for dust abatement
- Development of green belts
- Monitoring network.

The above improvements in the areas will further enhance the quality of mine environment in the North Goa iron ore mining belt.

### **5.1.5 CONCLUSION**

The case studies undertaken have helped in evolving pollutants emitters, pathways and receptors. The areas and factors requiring attention in Sukinda valley chromite belt in the main risk associated with hexavalent chromite in the water, and transfer of the pollutants throughout the food chain, including paddy fields, fruits vegetables and aquatic flora and fauna. Presently, treatment of mine water and process water is being done with the help of water treatment plants installed by the mining companies as a mitigation measure and the results obtained are far below the requirement.

In the case of Goa iron ore mines, the major problem associated with risk assessment is the dust pollution. The dust is mostly produced from the mining activities, waste disposal and lack of proper infrastructure facilities. The abatement measures include dust suppression in the form of water sprinkling on roads, waste dumps and covering the loaded trucks and developing the green belt.

The results of these investigations have clearly brought out the need of involvement of the mine management, state and central government agencies in evolving required standards and monitoring mechanism to ensure best practices in environment and sustainable development.

The methodologies developed in case studies will serve as a model in taking up similar studies in other mining areas in India.

## 5.2 THE TAILINGS POND FAILURE AT THE AZNALCOLLAR MINE, SPAIN

The accident occurred on 25 April 1998 in the installation of Boliden-Apirsa, which exploited a mine at Aznalcóllar, Boliden-Apirsa had acquired the mine in 1987, while the mine had been in exploitation for a considerable number of years already.

The mine produces zinc-, silver-, lead- and copper-concentrates from a pyritical ore body. The pyritical ore, which also contains arsenic, cadmium, thallium and other metals in lower concentrations, is broken in the mine installations and milled down to a rather fine grain. Then, different metal compounds are separated from this fine-grained ore with the help of a flotation process, where water is used, to which sulphur dioxide (SO<sub>2</sub>) calcium hydroxide (Ca(OH)<sub>2</sub>), copper sulphate pentahydrate and an organic compound are added as agents, in order to promote flotation.

At the time of the accident, the tailings (the waste resulting from the above process) was discharged into an artificial pond (tailing pond), a common method for managing and disposing of this type of waste.<sup>18</sup> The pond covered a surface of about 1.5 km<sup>2</sup> and contained, at the time of the accident, about 31 millions tons of sludge. Around this pond, a dam had been erected to contain the tailings; the dam was regularly increased, as more quantities of tailings were added. The main material that was used for the construction of the dam came from the mining activity itself.

In the night between 24 and 25 April 1998, the dam around the pond broke at a length of about 50m. Some three million m<sup>3</sup> of sludge and four million m<sup>3</sup> of acidic waters were discharged into the adjacent environment, where about 4.500 hectares of land on the border of the Coto Doñana National Park were polluted, and into the river Guadiamar. The major part of the sludge remained in the neighbourhood of the pond, where layers of sludge with a thickness up to two meters were found, the thickness decreased progressively with large parts of the affected land being covered with a layer of about 20 cm, but diminishing down to some millimetres. No damage to humans occurred. 2500 ha of the affected area was covered with tailings; the other 2000 ha were affected by acid waters but not by tailings. The spill entered the Agrio River, which flows into the Guadiamar River 4 km south of the tailings pond. The Doñana national park was not affected by the spill.

Local, provincial and regional authorities and the operator of the mine undertook emergency work to contain the sludge and waters, in particular in order to protect the natural reserve of Coto Doñana. Clean-up work continued during most of 1998 with additional re-cleaning of some areas in 1999. The sludge and contaminated soil were brought and disposed of in the old pit of the mine of Aznalcollar in the north of the tailing pond. The tailings pond is currently undergoing decommissioning. Following authorisation from the regional government of Andalusia, the mining operation restarted in 1999, temporarily using the old pit of Aznalcóllar for tailings disposal.

**Phase one . 1998:** The immediate damage had been done. Apirsa.s priority was to avoid secondary damage in the medium or long term. The spill had happened just as the rainy season was ending. <sup>19</sup>It was urgent to complete the cleanup before the next rainy season

began, and prevent the rains from causing the metals in any remaining tailings to leach into the environment. Apirsa built a private road to keep trucks off public thoroughfares. The waste was deposited for safe, approved storage in the depleted.

Aznalcollar open pit adjacent to the Los Frailes mine. By late 1998, more than 99% of the tailings in Apirsa's northern sector had been removed and safely deposited in the depleted Aznalcollar open pit. Site-specific criteria for metals in soil were established by Spanish environmental authorities providing guidance for further remedial actions. Chemical elements in soil and sediments have to respect the following criteria according to the near future land use. The clean up results show the rate of soils passing criteria.

Arsenic concentrations meet the criteria on at least 59% of the affected lands (on 73% of agricultural land). The remaining affected lands; mostly abandoned gravel pits, and may require additional remedial action in the future. This could involve chemical stabilization of arsenic and metals, possibly combined with the application of clean soil. Water quality in the river improved rapidly.

**Phase two. 1999:** With phase one of the cleanup completed, the rehabilitation phase has begun and will continue through 1999. Investigations to form the basis for resuming the agricultural use of the land began in 1998 with greenhouse tests using soil from various areas. Once rehabilitated, the land is expected to be safe for agriculture. The Spanish governmental authorities have, however, stated their preference to turn the area into a Green Corridor linking Doñana National Park with Sierra de Aracena y Picos de Aroche National Parks. An international panel was commissioned to review the environmental impact of the accident and the reclamation planning.

The Apirsa tailings ponds was designed and built in 1977-78. Boliden bought Apirsa in 1987. The tailings dam was regularly inspected. In 1996, independent experts conducted a full-scale stability study of the dam. No signs of instability were detected. At the recommendation of the study, Boliden installed extensive new instrumentation to enhance monitoring.

Apirsa assumed responsibility of cleaning up the northern sector below the tailings dam (an area of approximately 800 ha containing about 80% of the discharged tailings). The Spanish governmental authorities assumed responsibility for cleaning up the southern sector below the tailings dam (an area of approximately 1,800 ha containing the remaining discharged tailings). According to the final results of the in-depth expertise, all the geological parameters have not been taken into account during the conception of the dam, in particular geological structures. Indeed, the accident is due to a slip of the whole of the dam. The slip thus caused a breach in the dam.

It has been concluded that any mismanagement or other actions did not cause the accident. The cause of the accident was a slide in the subsoil 14m below the foundation of dyke. Neither the dyke itself nor the management was the reason for the failure. The mistakes committed were done already in the characterisation of the geotechnical properties of the underlying clay during the design phase in the seventies.

### 5.3 CYANIDE DUMPING AT THE BAIA MARE MINE, ROMANIA

A dam at the Aurul smelter of the "Baia Mare" goldmine at Sasar/Romania broke<sup>20</sup>. An estimated 100,000 m<sup>3</sup> of mud and wastewater with a 126 mg/litre cyanide load entered through de-watering channels into the Lapus River, a tributary to the Somes (Szamos) river and from there into the Tisza river and the Danube upstream of Belgrade and finally entered the Black Sea. The acute transboundary pollution had the potential of having a severe negative impact on biodiversity, the rivers ecosystems, drinking water supply and socio-economic conditions of the local population.<sup>21\</sup>

Romania, Hungary and the Federal Republic of Yugoslavia performed sampling and analyses. Measurements on 1 February 2000 at Satu Mare on the Somes showed a maximum concentration of cyanides reported to be 7.8 mg/litre (compare with maximum limit value for surface waters of 0.01 mg/litre). A 30-40 kilometre long contaminated wave wiped out flora and the fauna of the central Tisza River with damages estimated of hundreds of thousands of €. The cyanide plume was measurable at the Danube delta, four weeks later and 2000 km from the spill source.

Acute effects, typical for cyanide, occurred for long stretches of the river system down to the confluence of the Tisza with the Danube: phyto- and zooplankton were down to zero when the cyanide plume passed and fish were killed in the plume or immediately after. The Hungarian authorities provided estimates of the total amount of fish killed in excess of one thousand tons, whereas the Romanian authorities reported that the amount of dead fish reported was very small. According to the Yugoslavian authorities a large amount of dead fish appeared in the Yugoslavian part of the Tisza River. No major fish kills were reported from the Danube. Soon after the cyanide plume passed, the aquatic microorganisms recovered rapidly. Long-term effects on bio-diversity will have to be shown from further analysis. Environmental experts fear that some rare and unique species both of flora and of fauna have been endangered, e.g. the five ospreys living in the Hortobagy National park in Hungary. It is difficult to assess the exact damage caused by the accident as the river had been subject to long-term chronic pollution from the mining activities in the region.

Timely information exchange and precautionary measures taken by the Romanian, Hungarian and Yugoslavian authorities, including a temporary closure of the Tisza lake dam, mitigated and reduced the risk and impact of the spill. The water supply of the two largest cities along the Tisza River, Szolnok (120,000 inhabitants) and Szeged (206,000 inhabitants) was not endangered due to the prompt action of the local authorities.

Villages close to the accident site were provided with alternative water sources, but were allegedly not informed about the spill sufficiently early. Downstream drinking water was not affected because of the use of alternative supplies and deep wells.

Consequently, immediate human health risk seems to be minimal from this spill alone, but chronic health impacts due to long-term pollution by heavy metals are possible. The spill occurred in an area already contaminated with heavy metals from a long history of

mining and metal processing. Upstream locations unaffected by this particular spill also contained high levels of some heavy metals. Thus, the accident occurred in a region with a number of poorly maintained and operated plants and flotation ponds containing cyanide and/or heavy metals, many of which are leaking continuously. There is a risk of further pollution of surface and groundwater as well as soils due to continued leaking or acute accidents.

# Chapter 6

## **CONCLUSION AND RECOMMENDATIONS**

## **6.1 CONCLUSIONS/ RECOMMENDATIONS**

The mining sector is a major contributor not only to the material needs, but also to the development and economic growth of the European countries. On the other hand, it is obvious that exploitation of mineral resources requires a responsible approach to avoid adverse effects on the environment.

## **6.2. PRESENT STATUS**

The detailed study has been carried out on the present status of mining waste generation, management, legislation related to mine waste management and accidents impacts of mining wastes. The following are the outcomes of this study.

### **6.2.1. RISKS LINKED TO MINING WASTE**

An important conclusion of the study is that the major risks linked to mining waste (not all mine or all mine waste) are double:

- Risks linked to the liberation of acidity and heavy metals caused by the modification of the relationship between the minerals, the surface and ground water and the atmosphere (especially metallic ore). Such risks could correspond to a continuous and long-term pollution, which will not stop before total oxidation of the waste exposed to the atmosphere. This risk is the combination of a potential source of pollution with transfer pathway and the existence of targets (human here).
- Risks linked to the stability of the tailings dam. Such risks could create spectacular accidents as those occurred recently in Spain and Romania.

#### **a. Liberation of acidity and heavy metals**

A specific characterization of representative waste samples resulting from mining, quarries and ore processing operations should be carried out on each site. Such characterization should include specific studies related to the potential of pollution of the waste. Not only the solid composition but also the nature of the leachates resulting from mining waste should be defined (as it is a common practice for industrial waste within the framework of the Landfill Directive) and be correlated to the quantity of corresponding waste. Indeed, the effluents resulting from deposits of mining waste may be acid and contain heavy metals in significant quantities, with a potential impact on the environment. The leachate of mining waste will also depend on the waste management practices implemented.

#### **b. Stability of the tailings dams**

It seems necessary, at the scale of EU, to have a global estimation of the risks presented by the stability of the different existing tailings dams. Experience sharing must be promoted. The two recent accidents, which have occurred in Spain and in Romania, were

directly linked to the stability of tailings dams, under very different geological, climatic, legal and administrative circumstances. We could consider that the stability conditions of the tailings dams are today well defined<sup>28</sup> and should be part of minimum technical requirements. In each member states, it is the responsibility of the National authorities to assess the corresponding risks. In addition, an approach at EU level seems necessary to address this issue.

### **6.2.2. THE DIFFERENT TYPES OF MINE**

It is obvious that the pillar of sustainable development related to the protection of environment has not always been sufficiently considered, in particular in the past. As a consequence, a distinction should be made between the following three types of mines:

- Abandoned/ old mines,
- Operating mines substantially based on old designed operations,
- Operating mines based on new design.

1. Serious problems are arising from abandoned mines and mines which activity is based on old operations which have been conceived without environment management. There is a need of basic criteria for mine closure plans, which can be based on the methodological approaches such as defined in European working groups like CARACAS (Concerted Action on Risks Assessment for Contaminated Sites) or CLARINET (Contaminated Lands and Risks Network for European Technologies). In particular, for abandoned mines, it is important:

- to establish objectives for required future land use and not accept multi functionality of sites,
- to undertaken survey (including land form, geology, soil types, hydrogeology, flora and fauna components, existing land use, heritage, characterisation of overburden and waste material, recycling potential,..) to obtain a clear picture of the situation.
- The following methodology is proposed :

- \_ Inventory of the sites (location, types of facilities, waste),
- \_ Prioritisation of the sites in term of general environmental impacts and risks,
- \_ Evaluation of the risks (including dam safety) and measures to be taken,
- \_ Remediation plans to address the most problematic sites.

2. For operating mines substantially based on old designed operations, it is essential to evaluate the reliability of the control routine related to the stability of the tailings dams. It seems also necessary to improve the waste management conditions of these sites. Relatively diverse situations do exist in the EU and between sites in the same countries, in terms of environmental protection.



3. Existing mines based on new design ensure a higher level of environmental protection. However, these sites should also be evaluated with the views of taking additional measures if necessary. The closure phase should also be carefully prepared. This is often taken into account.

### **6.2.3. RESEARCH AND DEVELOPMENT**

The recycling of valuable elements of the waste should be encouraged, through R&D efforts. Certain waste contains elements which could be very useful for the industry and which are obtained from other sources at a non-negligible energetic and environmental cost. Environmental disequilibrium is created rather by the physicochemical changes related to the extraction of the ores than by the chemical substances added during the processing. This could be further studied.

Research and development programs must be built on sets of themes, specific to the various methods of mining waste management.

### **6.2.4. LIMITS OF THE METHOD**

This report is based on country-by-country inventory, within the European Union, of sites associated with the management of mining, quarrying and ore-processing waste. It represents the first overview of the current situation in Europe as regards mining waste and presents the current regulatory and management measures specific to each country. The survey involved two approaches:

- a questionnaire related to the quantities of existing waste, associated with the typology of the mined substances, deposits and mining systems and ore processing methods,
- an estimation, on the basis of the different processes employed throughout the production chain in mining operations and their management at each level, of the main types of waste generated over the last five or ten years.

The data provided by the questionnaire is very diverse, heterogeneous and not easy to assess and compare. To get a reliable set of information of the EU situation regarding the mining waste disposal, we also have been extrapolating the current production data in order to get a preliminary estimate of what could be the waste production, over the last five or ten years.

The comparison of this estimate with the data issued from the questionnaire shows several differences, which are due to:

- Different kinds of mining waste, both from exploitation and processing,
- Different approaches and definitions. Several materials, which can be called waste, have an important potential of recycling within a given environmental and

economic framework and are not regarded locally as waste despite the legal definition of waste.

### **6.3 EVALUATION OF THE LEGISLATION**

The second aim of the study was to evaluate the current national and EU legislation on mining waste. It is necessary to find a compromise between the approach by legislation and the approach by Best Available Technologies. Legislation fix objectives and rules, and BAT present the technical aspects (as said earlier, legislation and guidelines do exist in Australia, Canada, Norway, Sweden and the United States).

In EU countries, the mining industry is currently regulated by either mining codes, which include waste management regulations, or by general environmental regulations.

The control of the environmental impact of mining waste has known a recent development within the European Commission. This is why, it is suggested to consider the conclusions of the different studies and corresponding laws, done in developed mining countries such as Canada, the USA or Australia where programmes have been carried out and are going on, in particular the programmes MiMi (Mitigation of the Environmental Impact from Mining Waste) (Swedish programme) or MEND 2000 (the Canadian Mine Environment Neutral Drainage Programme) (see Proceedings from the fifth international conference on acid rock drainage . ICARD 2000. ISBN 0-87335- 182-7)30. Various initiatives relating to the development of a Code of Practices of environmental management are under development within some mining companies, in particular European mining companies. At the European legislative level, the management of mining, quarrying and ore processing waste is included in the initial Environmental Impact Assessment of industries. These systems do already exist in some countries of European Union. In addition, there is a strong case for seeking to secure minimum requirements for good practice based on careful review of the most successful aspects of minerals planning in each country. The European Commission is currently following this approach in its initiatives announced in the Communication on the safety of mining activities.

There is a need for a thorough assessment to be made of the impact of sustainable development policies relevant to minerals, possibly leading to the formulation of a European policy on sustainable exploitation and consumption of minerals. The European legislation has vocation to be applied to the Central and Eastern European countries, candidate for integration. For some of them, the mining activity plays an important social and economic role. During the time of the planned economy, the environmental management was practically non-existent. Putting into practice the European standards in the field of the mining activity should follow an appropriate timetable.

## 6.4 MAIN OUTCOMES

According to the above, the recommendations are:

1. To validate this inventory study of the sites of mining waste deposit in each country, by detailed study carried out by a homogeneous multidisciplinary team, especially for abandoned and closed mines,
2. To get information for each site, on solid composition but also on the nature of the leachates resulting from specific and representative mining waste samples (according normalized European leaching and long term tests),
3. To evaluate different evolution forms of legislation (based on BAT),
4. To define basic criteria for mine closure plans, on the base of European contaminated lands approach,
5. To organize meetings and exchanges of information between industrials and researchers of the Member States (as the task forces after Spanish and Roman accidents),
6. To start research and development programs on sets of themes, specific to the various methods of mining waste management, including an improvement of recycling techniques. The themes that have to be studied are related to main generic issues:

- **Design of tailing and waste rock facilities,**
- **Waste management** (characterization of the reactivity of specific mining waste by different ways leaching test, long term column test and normalized tests of the Landfill Directive, improvement of recycling technique of mining waste and assessment of current after-care practices),
- **Dam stability** (study of influence of exceptional meteorological conditions on the stability of dams),
- **Water management** (study of the behaviour of heavy metals coming from mining waste in the subjacent geologic layers and the prediction of their becoming by tools like geochemical and solute-transport modelling),
- **Closure Plan**

# Chapter 7

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